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Impact of Advanced Technology Use on Firm Performance in the Canadian Food Processing Sector

by John R. Baldwin, David Sabourin and David Smith

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Abstract

This paper investigates the evolution of industrial structure in the Canadian food processing sector and its relationship to technological change. It does so by examining the impact of adopting advanced manufacturing technologies, amongst them information and communication technologies (ICTs), on plant performance.

This study utilizes a linked dataset combining advanced technology use data from a 1998 special survey with firm performance data derived from administrative records covering the period 1988-1997. The data file contains information on advanced technology use (by type of technology), plant characteristics (size, nationality, emphasis given to training, innovativeness) and plant performance (growth in productivity and market share).

The paper first examines the characteristics of firms that adopt advanced technologies. It then asks how the use of these technologies is related to growth in productivity and market share.

Plants that adopted advanced technologies were larger and foreign controlled. They tended to be more innovative along a number of dimensions other than just their technological orientation. They were the ones that adopted a number of advanced business production processes that made use of advanced technologies. They were plants that developed a human resource strategy that focused on developing a skilled workforce and emphasized training.

Plants that adopted more advanced technologies enjoyed superior productivity growth. Process control and network communications technologies are particularly important to productivity growth in the food-processing sector. Those plants that increased their relative productivity growth and used more advanced technologies saw their market share increase.

Once technology use was taken into account, few of the other characteristics of plants that were related to technology use contributed to increased relative productivity growth—except for the emphasis given to a human resource strategy that focused on the development of skilled labour and training. Similarly, apart from technology use, none of the plant characteristics that are related to the use of advanced technologies were related to the growth in market share.

Keywords: productivity growth, advanced technology, food processing, market share

Executive Summary

Food Processing: A mature industry

Food processing is Canada's third largest manufacturing industry, consisting of more than 3,000 establishments. Employing close to 230,000 people in 1998, it boasted a gross domestic product of $15 billion that same year. The food processing industry is a mature industry, typified by modest-sized plants and moderate growth over the past couple of decades. Its links to the global economy, whether measured by trade or foreign investment, are below the manufacturing average. It may appear that the food-processing industry has lagged other industries in introducing automation. Indeed, many of the processes in this industry are so complex that they are regarded as more of an art than a science. Despite this, new products and processes are constantly being developed and introduced in the food-processing industry.

Change taking place—half of market-share shifts

There is considerable change taking place, at the establishment level, within the Canadian manufacturing sector as some plants wrest market share away from others. The same is true for the food-processing industry. Market share changes hands as some plants grow, while others decline. Between 1988 and 1997, about one-third of market share had been transferred from decliners to gainers. Use of advanced technology contributed to this process.

Adoption of advanced technology is thought to contribute to superior firm performance that sees some firms replacing others. Until now, the data to investigate this presumption has largely been unavailable. This study uses a new set of data to address this issue. Two measures of firm performance are used in this study—productivity growth and market-share growth—and the paper related the use of advanced manufacturing technologies to these measures of performance.

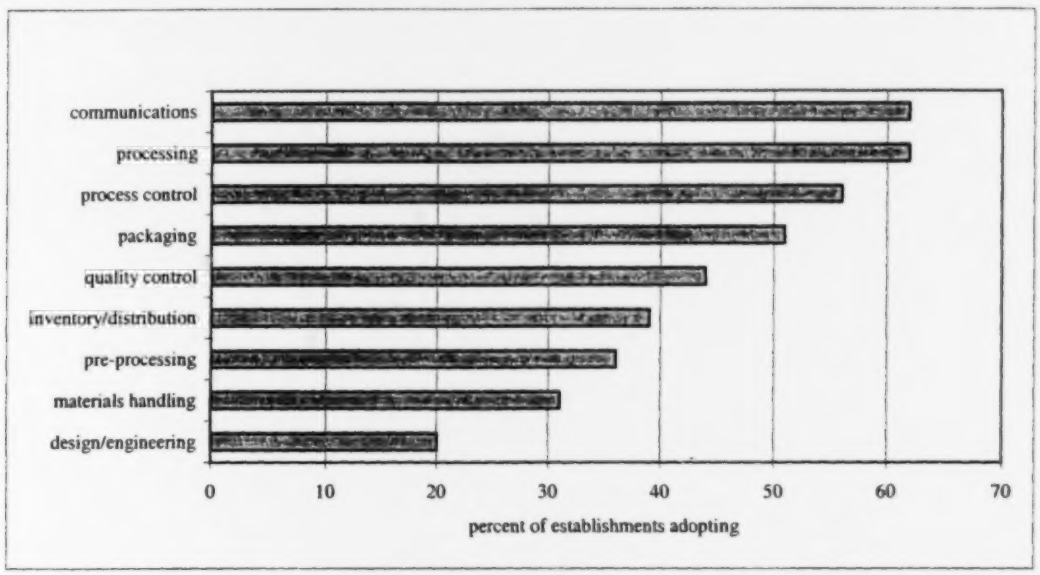
Technology use and adoption rates

By the end of the 90s, nine-out-of-ten food-processing establishments adopted at least one of the sixty advanced technologies identified on the 1998 Survey of Advanced Technology in the Canadian Food Processing Industry. Seven percent used 20 or more. Adoption is highest for local area networks, programmable logic controllers, and the use of advanced materials for packaging. At least one third of establishments had adopted these technologies by the late 90s.

In terms of broad technology categories, adoption rates were greatest for network communications and processing technologies, with 62% of food-processing plants adopting at least one technology from each of these two areas (Figure 1). Communications technologies include local and wide area networks, while processing includes the likes of advanced filter technologies, thermal preservation techniques, and the use of bio-ingredients. Process control and packaging are next, both with adoption rates of more than fifty percent. Programmable logic controllers and computerized process control were the most widely-used process control technologies, while the use of multi-layer materials and laminates were the most popular advanced packaging technologies.

Adoption rates varied across plants. Large establishments were not only more likely to adopt advanced technology, they were also more likely to adopt them in higher numbers. Size differences are largest for communications, process control, and design and engineering technologies. Nationality also matters, as foreign-controlled plants were more likely to adopt, even after controlling for their larger plant size.

Figure 1. Advanced Technology Use



Use of ICTs associated with higher productivity growth

Earlier studies, conducted in a number of different countries, find evidence of a positive link between the use of advanced technology and enhanced firm performance. There is a strong presumption that a similar relationship also exists for the food-processing industry. Indeed, the analysis revealed that plants that adopted higher numbers of advanced technologies enjoyed higher productivity growth. Certain types of technology were found to have more impact on growth than others. Adoption of information and communication technologies (ICTs), such as local and wide area networks and inter-company computer networks, are positively associated with higher productivity growth throughout the 1990s. Transfer of information both within and between organizations is closely associated with productivity growth. Adoption of advanced process control and advanced packaging technologies are also linked to higher productivity growth.

Productivity growth and market-share growth strongly linked

Adoption of advanced technology and market-share growth are found to be related. Yet the predominant story here is the strong relationship that exists between productivity growth and market-share growth. Productivity growth is associated with market-share growth. Plants that adopted advanced technology by the end of the 1990s were more likely to have enjoyed higher productivity and, as a result, gained in market share throughout the decade.

Other characteristics also have impact

In addition to technology use, several other characteristics were found to be related to higher productivity growth. Consistent with the literature, growth in capital intensity has a large and significant effect on productivity growth. Implementation of an aggressive human resource strategy, one that values continuous improvement of the workforce, through training and recruitment, is also associated with higher productivity growth.

1. Introduction

The choice of a successful strategy is key to a firm's growth. One of the strategies that we have found to be related to growth is innovation (Baldwin, 1996, Baldwin and Johnson, 1999a). One successful innovation strategy revolves around the use of advanced technologies.

This paper examines how an advanced technology strategy in the food-processing sector is related to superior firm performance. It builds on two previous streams of research. The first are the studies that examine the characteristics of firms that are more innovative, either in the sense of introducing new products or new processes, or in terms of introducing new technologies. The second is the research that examines the connection between innovation and firm performance. Our work in both these areas conditions our view of the forces that are operating to influence dynamic change in the population.

Firms have choices to make with regards to the strategies that they follow. Some try to be more innovative than others. To be successful innovators, firms have to combine a number of competencies (Baldwin and Johnson, 1998, 1999a, 1999b). They have to develop the capabilities to innovate—either by investing in R&D or in their technological capabilities. But they also have to develop special capabilities on the human-resource side, and in marketing and finance.

Decisions on which strategic competencies are developed are then reflected in a firm's performance. Growth is a stochastic process that involves learning. Production opportunities are not unique and the growth of individual firms occurs in a world where each explores which advanced technologies and other strategies out of a set of many technological possibilities and strategies might be the most suitable to its circumstances. Firms adopt new, advanced technologies as they learn about their possibilities and experiment with the applicability of the new advanced technologies to their specific situations. Experimentation rewards some firms with superior growth and profitability. Market forces cull those firms that have made the wrong choices and reward those who have correctly chosen those policies that work.

This paper is meant to replicate and expand upon earlier work that finds performance is related to technological choice (Baldwin and Sabourin, 2001; Baldwin, Diverty and Sabourin, 1995). In these papers, we find that manufacturing plants that had adopted advanced manufacturing technologies, in particular information and communications technologies (ICTs), experienced faster growth in productivity and in market share than those plants that had not managed to incorporate these advanced technologies into their plants. The first of these two papers examines this connection in the 1990s; the second does so for the 1980s.

Here, we examine a specific sector—the food processing sector—and extend our earlier work that focused on all manufacturing industries in two ways. First, by focusing on a specific sector, we are able to examine a far more extensive list of technologies. The earlier work had to focus on a core set of about 20 technologies that were common across a wide range of industries. Here we examine a group of more than 60 technologies. Second, we focus on how groups of technologies interact. Imbedded in the list of technologies examined are a number of industry-specific technologies (infra-red heating) plus most of the technologies previously examined. In

particular, information and communications technologies (ICT), which were found in the two previous studies to be key to growth, are included. This enables us to examine not only whether ICT matters, but also which other technologies it complements.

The focus of this paper is on technology choice and its consequences for performance. While R&D is often stressed as a key activity for innovators, technological capabilities are just as important. Baldwin, Hanel and Sabourin (2000) demonstrate that the probability of becoming an innovator increased by about 20 percentage points if a firm goes from placing little emphasis on technology to a much greater emphasis on technology, while performing R&D has about a 30 percentage point effect. Baldwin and Hanel (2003) stress that a technological focus is a unique way, often quite separate from R&D, by which firms develop innovations.

While our focus is on technology, we recognize that other factors may impact on performance. Fortunately, the *Survey of Advanced Technology in the Food Processing Sector* (see Baldwin, Sabourin and West, 1999) that is used for this paper allows us to also examine the relative importance of other factors—such as whether a firm is conducting R&D, developing a cadre of skilled workers, or has adopted advanced business practices.

This paper is organized as follows. The first section examines certain characteristics of the stochastic process that are relevant to the measures of firm and plant performance that are used in this paper. Before we examine whether technology choice is related to changes in market position, we examine the amount of change that is taking place within the food processing industry. The second section enumerates the extent to which plants replace one another by transferring market share from one to another over the ten-year period from 1988 to 1997 and the extent to which this has been accompanied by changes in relative productivity and profitability.

The paper then studies the effect of technological choices on plant performance—using measures such as growth in productivity and market share. It examines the relationship between the use of advanced manufacturing technology—such as programmable controllers, aseptic processing, and local and wide area networks—and these two measures of plant performance. It investigates whether plants using advanced technologies, in effect, are selected for survival and growth by the search and culling process that is associated with competition.

The economic performance data used in the study come from a longitudinal file developed from the *Annual Survey of Manufactures*, which includes data on employment (production and non-production), labour productivity (value added per worker), wages and salaries, manufacturing and total shipments, and manufacturing and total value added for Canadian food-processing plants during the period 1988 to 1997.[1] These data allow us to develop an objective measure of actual plant performance, as opposed to subjective measures derived from an evaluation by the survey respondent of their performance relative to competitors. The objective economic performance data were linked to data on advanced technology use at the plant level derived from the *1998 Survey of Advanced Technology in the Canadian Food Processing Industry*. In what follows, we will be using plants as the unit of analysis. The results are weighted so that they represent the population of plants in the food-processing sector.

[1] Total value added differs from manufacturing value added because of non-manufacturing activities of manufacturing establishments that are intrinsic to the manufacturing operations of the firm.

2. *Market Turnover*

This study of the relationship between technology use and changes in firm performance examines whether firms that adopt advanced manufacturing technologies perform well relative to their colleagues—both in terms of relative productivity growth and market-share growth. This question is only interesting if there is extensive change taking place within industries—if some firms are dispossessing others. In this section, we discuss the amount of change that was taking place in the food-processing sector during the 1990s.

Previous work (Baldwin, 1995) has demonstrated that considerable change is taking place over a ten-year period within the manufacturing sector. This is also the case for the food-processing sector. Growth and decline takes place as some plants wrest market share away from others. The amount of change is large. Between 1988 and 1997, 43% of continuing food-processing establishments saw their market share decline, 48% enjoyed an increase in their market share, while 9% had no appreciable change. Market share is also transferred via entry and exit. During the period 1988-1997, some 32% of market share was transferred, on average, from those losing market share to those gaining market share measured at the 4-digit industry level.[2] Growing continuers accounted for 20 percentage points of the gain, while entrants accounted for the remaining 12 percentage points. Decline in market share, on the other hand, comes from declining continuers (13 percentage points) and exits (19 percentage points).

Plant growth and decline leads to changes in the relative rankings or positions of industry participants (Table 1). Plant market shares at the 4-digit level are calculated for 1988 and again for 1997 and then all establishments are assigned to quartiles in both the start year (1988) and the end year (1997) of the period, based on the rankings of their market share.[3] Table 1 describes the movement of continuing establishments up and down the market-share hierarchy, that is, the percentage of continuing plants that stayed in the same quartile, or moved up or down one or two quartiles.

Throughout the decade, there has been substantial change in relative size. For example, of those continuing plants that were in the second quartile in 1988, 15% fell to the bottom quartile in 1997; 17% moved up to the third quartile; while 66% remained in the same quartile.

Table 1. Market Share Transition Matrix for Continuers (1988-1997)

Market Share Quartiles (1988)	Market Share Quartiles (1997)			
	Q1	Q2	Q3	Q4
	Percentage of establishments			
Q1 (BOTTOM)	72	23	5	0
Q2	15	66	17	2
Q3	2	17	60	21
Q4 (TOP)	1	2	14	83

[2] Industry structure is measured at the establishment level (SIC-E).

[3] In Table 1, the quartiles are calculated using all establishments, but the shares are calculated only for continuers.

There is somewhat more inertia in the plants that started in the bottom or top quartile—partially because their movement possibilities are truncated, either in an upwards direction for the top quartile or downwards for the bottom quartile. Over eighty percent of the plants in the top group remained there, while close to three-quarters of those in the bottom group did likewise.

Market share changes hands as some firms develop a competitive advantage over their compatriots. One of the factors that facilitate the development of competitive advantage is productivity growth. Firms that gain productivity relative to their competitors can put that advantage to work by dropping prices or increasing quality and thereby gain market share.

The question then is to what extent do we see a substantial change in relative productivity? Is the amount of this change large or small. If it is quite small, either we have little prospect of explaining the amount of change in relative productivity by the adoption of advanced technology, or it is an uninteresting question.

The amount of change in relative labour productivity was investigated using the same type of transition matrix that was applied to market-share changes. Labour productivity is defined here as total value added divided by total employment. It is calculated for each plant relative to its industry's labour productivity. Changes in relative labour productivity will occur as a plant becomes more efficient or if it increases its use of capital and other inputs relative to other plants in the industry.

While some might prefer a total or multifactor productivity estimate to capture pure technical change, there are reasons for our preference of a labour productivity measure. First, the two are related in a simple way. Labour productivity growth is just the growth in total factor productivity plus the share of capital times the rate of growth of capital intensity. Labour productivity then encompasses a broader concept than multifactor productivity. Labour productivity increases both because multifactor productivity increases and because capital intensity of a firm increases. And most firms grow from small to large entities by learning how to apply more capital to their operations as well as by increasing their efficiency. Therefore to the extent we are interested in market-share growth, labour productivity growth is a more intuitive concept to employ. Second, labour productivity is more accurately measured than total factor productivity—especially at the firm level. Multifactor productivity is difficult to measure accurately at the industry level because it needs estimates of depreciation rates. At the firm level, these estimates are almost impossible to obtain.

The transition matrix for the relative labour productivity of continuing plants between the years 1988 and 1997 is provided in Table 2. Ranking establishments according to their relative labour productivity in each of 1988 and 1997, and assigning them to quartiles in each of the two years, the transition matrix provides the percentage of establishments that had bettered their relative position, stayed the same, or declined. Relative labour productivity is calculated for the 4-digit industry in which the plant is located for both years.

As evidenced by Table 2, a substantial percentage of plants shifted position with regards to relative labour productivity. For continuers, more than half of the plants shifted up from the lowest quartile, while half shifted downward out of the top quartile. The movement was even higher for the middle two quartiles, with only a third of plants still remaining in the same quartile in which they had started.

Table 2. Relative Labour Productivity Transition Matrix for Continuers (1988-1997)

Relative Labour Productivity Quartiles (1988)	Relative Labour Productivity Quartiles (1997)			
	Q1	Q2	Q3	Q4
	Percentage of establishments			
Q1 (BOTTOM)	46	28	15	11
Q2	26	34	25	12
Q3	12	28	32	28
Q4 (TOP)	8	12	27	53

To this point, we have examined changes in market share and changes in productivity independently of one another. But changes in relative productivity and changes in market share should be related. Success in terms of the growth in market share is accomplished in various ways. Plants may attract customers either through lower prices or by offering higher quality products. Higher levels of labour productivity permit a firm to offer either or both lower prices and higher quality. In either case, we would expect changes in a firm's relative productivity to be associated with increases in market share on average.

To illustrate how the gain in market-share is accompanied by a growth in relative labour productivity, we divide continuing plants into two equal groups based on whether they gained or lost market share over the period (growers versus decliners). Two questions are examined. The first is whether differences in labour productivity at the beginning of the period provide any signals as to who is likely to do better over the period? The second is whether firms that improve their relative productivity also gain market share.

We find that the relative labour productivity of growers is lower than that of decliners at the start of the period (Table 3). Opening-period success with regards to relative productivity is not a good indicator of growth in market share over a subsequent period. But, by the end of the period, those gaining market share simultaneously manage to increase their relative productivity. By 1997, their relative productivity is well above that of the declining group. The market has rewarded those who have managed to improve their labour productivity with an increase in market share.

Table 3. Mean Relative Labour Productivity by Growth in Market Share

Market-share Change (1988 to 1997)	Relative labour productivity (RLP)		ΔRLP
	1988	1997	1988 to 1997
LOW GROWTH	1.078	0.927	-0.151
HIGH GROWTH	0.909	1.043	0.134

All of this suggests that there is a close relationship between changes in relative productivity and market-share growth—but that the relationship is one that is best investigated by examining the growth in market share over a period and the differences in characteristics that have emerged by the end of the period. The market rewards correct choices—but the evidence for this emerges only by the end of the period.

3. Data Source for Advanced Technology Use

We focus, in this paper, on the adoption of a list of advanced technologies developed specifically for the Canadian food processing sector—a two-digit SIC manufacturing industry. Since this survey covers only the food-processing sector, it is possible to 'customize' the list of advanced technologies to include technologies specific to this industry by working with representatives of the industry. Although by no means exhaustive, the list of technologies presented on the questionnaire is felt to be representative of the advanced technologies available to food processors.

In this study, we make use of the results of the *1998 Survey of Advanced Technology in the Canadian Food Processing Industry* conducted by Statistics Canada to measure the extent to which advanced technologies have been integrated into the production process. The survey is based on a frame of Canadian food processing establishments drawn from Statistics Canada's Business Register. The sample was randomly drawn from a population of food processing establishments that was stratified by four-digit SIC industry, size and nationality of ownership. Excluded from the target population were food-processing establishments with fewer than 10 employees. The overall response rate to the survey was 84%.

The survey covered questions about advanced technology used, general firm and establishment characteristics, about skill development, the use of various business practices, as well as questions about the benefits and obstacles to the adoption of advanced technologies (Baldwin, Sabourin and West, 1999).

Sixty advanced technologies are listed on the survey covering nine functional areas (Appendix A, Table A1). The list of technologies examined was more extensive than those examined in the *1989 Survey of Advanced Technology*, the *1993 Survey of Innovation and Advanced Technology* and the *1998 Survey of Advanced Technology*, each of which surveyed manufacturing industries across a wide range of industries.

The nine functional areas covered in the *1998 Survey of Advanced Technology in the Canadian Food Processing Industry* are: processing, process control, quality control, inventory and distribution, information and communications systems, materials preparation and handling, preprocessing, packaging, and design and engineering. Within each of these areas were questions on the use of up to fourteen specific individual technologies. For example, within processing, plant managers were asked whether they used five different types of thermal preservation technologies, four different types of non-thermal preservation technologies, six different types of separation, concentration and water removal technologies, and two different types of additives.

Adoption of at least some advanced technology is high in the food-processing sector. Nine out of ten establishments in this sector have adopted at least one of the 60 technologies listed on the questionnaire. Among the functional groups, information and communications, and processing led the way with 62% of establishments having adopted at least one technology from each of these two groups.

Among ICTs, local area networks top the list at 43%, followed closely by inter-company computer networks at 37%. Being able to communicate and pass information within different parts of an organization and between different organizations is essential for doing business in today's economy. The fact that these two technologies have the highest adoption rates of all confirms the importance of ICTs in the workplace today.

4. Technology Use

Technology use in this study is measured first as the number of advanced technologies that had been adopted. But this method does not allow us to effectively measure how different technologies are being used in combination, one with another.

An alternative method for handling the complexity posed by a list of 60 technologies is to use principal component analysis to examine how different combinations or dimensions of technology use relate to firm performance.

Principal component analysis can be used to examine the dimensionality in a set of variables. In this case, it is used to investigate the various combinations of technologies that are being adopted by establishments in the food-processing sector. Principal component analysis creates a new set of variables, called principal components, which are a weighted average of the original variables. The principal components are constructed in such a way that they are orthogonal to each other and they capture all the variance in the original set of variables (see Appendix B). Examination of the relationship between technology principal components and firm performance allows us to determine which combinations of advanced technologies are related to productivity growth.

The eigenvectors used in the construction of the technology-use principal components are given in Table B1 (Appendix B). Interpretation of the principal components is provided in Table B2 of Appendix B. For example, the first principal component jointly captures the use of advanced process control, information and communications and packaging technologies. The second principal component captures the combined use of advanced processing technologies, of all types. But at the same time it represents plants in which advanced packaging machinery, robots and the use of CAD output for procurement are not important.

Use of various combinations of technologies, as represented by the principal components, vary across industries (Table B2, Appendix B). And they do so for two main reasons. First, some of the technologies are specific to certain industries, such as is the case for bran removal for the cereal industry and animal stress reduction for the meat industry. Second, some industries use the technology more intensively. Baldwin, Sabourin and West (1999) report that dairy plants and

fruit and vegetable plants are the most likely to adopt advanced technologies of many types, while fish and bakery plants are among the least likely to do so. They conclude that the dairy and the fruit and vegetable industries are the leaders when it comes to the adoption of advanced processing and advanced process-control technologies. The 'other' food products industry is the leader when it comes to the use of information technologies.

The first principal component, which explains 14% of the variance in the original set of variables representing each of the 60 technologies, captures the use of advanced process control, information and communications, and packaging technologies. Industry mean values for this principal component are highest for dairy and 'other' food products, and lowest for bakery and fish.

The second principal component, which explains 6% of the variance, emphasizes the use of advanced processing technology, of all types. It downplays the use of robots and packaging machinery. Once again, the dairy industry has the highest score, followed closely by the meat industry.

Examination of the top ten principal components reveals the following industry patterns. Establishments in the dairy industry favor four types of technologies—processing, process control, information and communications, and processing technologies. Use of advanced pre-processing technologies, on the other hand, is much less important. Non-thermal preservation technologies, such as ultrasonic techniques, also are less important.

Like dairy, the meat industry also relies on advanced processing technologies. But, unlike the dairy industry, it is the non-thermal preservation technologies that are among the most important. Separation and concentration processing techniques receive lower scores. Pre-processing technologies, in conjunction with non-thermal preservation technologies, receive higher scores.

Just like the dairy industry, the 'other' food products industry emphasizes the use of advanced process control, information and communications, and packaging technologies. It differs from the dairy industry in terms of its reduced emphasis on advanced processing technologies.

In the fruits and vegetables industry, the emphasis is on thermal preservation processing techniques. This is an industry that favors the use of infrared and ohmic heating, and even microwave drying, while downplaying the use of advanced design and engineering technologies, and non-thermal preservation techniques such as ultrasonic techniques and the use of chemical antimicrobials.

Pre-processing and process control technologies, rather than thermal preservation or advanced materials packaging, are more likely to be found in the bakery and cereal industry. Firms in this industry adopt pre-processing and process control technologies, but are less likely to adopt thermal preservation technologies and advanced materials packaging. The bakery industry also combines information and communications technologies, thermal preservation heating technologies and design and engineering technologies, while avoiding advanced separation techniques, testing techniques and the use of advanced materials for packaging.

The fish processing industry shares some commonality with the meat industry. Both emphasize pre-processing and non-thermal preservation technologies. Both downplay the use of advanced separation and concentration processing technologies.

5. Performance and Technology Use

This study builds on our previous work that finds firm performance is related to the innovative stance of a firm.

There are many factors behind the growth of firms and plants—from overall management capabilities, to marketing, human resources, and operational capabilities. A substantial part of a firm's capital consists of these internal competencies. These capabilities extend beyond just R&D performance to encompass those activities that enable a firm to ingest new information and to act quickly and effectively on it. In turn, advantages in this area are postulated to be associated with different levels of performance.

Despite the importance that has been attributed to a large number of factors behind success in the theoretical literature, our Canadian studies have consistently found that the innovative capabilities of firms are related to their success. Earlier studies have investigated the difference in the competencies found in growing and declining firms to see whether a key difference between the two lies in the nature of their innovation regime. These studies use three different surveys as sources and find similar results in each case.

Baldwin (1996) and Baldwin and Johnson (1998) find that while firms need to do many things better in order to succeed, innovation is the one factor that appears to discriminate best between the more-successful and less-successful firms. Baldwin, Chandler et al. (1994) study growing small and medium sized firms in the 1980s and find that the key characteristic that distinguished the more-successful from the less-successful was the degree of innovation taking place in a firm. Measuring success as a vector of characteristics such as market-share growth and relative productivity growth, they report that the more-successful firms tend to place more emphasis on R&D capability and R&D spending. They are also more likely to give more importance to developing new technology.

Johnson, Baldwin and Hinchley (1997) report that in new firms that entered in the mid 1980s and survived into their teen years in the 1990s, growth in output was closely related to innovation. Faster growing entrants are twice as likely to report an innovation, and more likely to invest in R&D and technology than slower growing firms. However, faster growing firms are also more likely to place higher emphasis on training, recruiting skilled employees and providing incentive compensation programs (Baldwin, 2000).

These findings regarding the importance which firms give to innovative strategies and activities are confirmed by two other studies that use data at the plant level on the use of advanced technologies. Advanced technology use is a form of innovation. These studies report that plants using advanced technology both grow faster and increase their productivity relative to plants not

using advanced technologies (Baldwin, Diverty and Sabourin, 1995; Baldwin and Sabourin, 2001).

In summary, all these studies have found that firms that manage to grow more quickly simultaneously *develop* certain innovative competencies that distinguish them from firms that grow less quickly. Differences in technological competencies have the same effect. That innovative and technological competencies are linked is not surprising. Some 53% of respondents to the *1993 Survey of Innovation and Advanced Technologies* who had indicated that they introduced the advanced technologies did so in conjunction with the introduction of a product or process innovation.

These findings, based on Canadian empirical evidence, are confirmed by research that covers the experience of other countries. Stoneman and Kwon (1996), Rischel and Burns (1997), Ten Raa and Wolff (1999), Van Meijl (1995), and McGuckin et al. (1998) find a positive relationship between advanced technology use and superior firm performance.

On the basis of these studies, there is a strong presumption that advanced technology users in Canadian food processing industries as of 1998 should have had superior performance during the 1990s. Measuring performance by productivity growth and by market-share growth, we examine the extent to which this relationship holds. Growth is defined as the change in market share over the period 1988 to 1997—a period of ten years prior to the survey date of 1998. In order to correct for industry effects, growth is defined in terms of market share, as calculated at the 4-digit 1980 SIC industry level, and measured as the difference between end- and start-period market shares. Similarly, relative labour productivity is calculated as total value added divided by total employment for the establishment divided by the same measure calculated at the 4-digit industry level.[4] Growth in relative labour productivity is calculated as the difference between end-period relative labour productivity and start-period relative labour productivity.

In what follows, we compare the performance of plants throughout the nineties to their technological profile at the end of the period. We have seen that differences in the productivity performance of growers and decliners do not exist at the beginning of the study period but emerge over the period studied. This accords with a world in which firms experiment with alternate advanced technologies and the market rewards those who have chosen the correct technologies and managed to get them to work in the appropriate fashion. At the end of any period, productivity differences are evident between those who have managed to gain market share and those who lost market share. For this reason, this study examines the differences in advanced technology use at the end of the period and the changes that have occurred in market share and changes in relative labour productivity over the previous time period. This procedure will show whether advanced technology use is associated with improved performance.[5]

[4] Defined as census total value added for manufacturing operations divided by total employment of both salaried and production workers.

[5] It cannot ascertain how changes in technology use affect performance. It is, of course, likely that changes in advanced technology use matter at the margin —though to ascertain how important the latter are, we need a longitudinal database. A separate study is using such a database.

We proceed in two stages—first, with bivariate analysis comparing different measures of performance to advanced technology use; and then with multivariate analysis that regresses performance measures on advanced technology use and a number of other plant characteristics.

Bivariate results of the relationship between economic performance and advanced technology adoption are provided in Table 4. Two separate measures of performance are used—growth in relative labour productivity (column I), and growth in market share (column II) over the period 1988-1997. In each case, establishments are divided into two equal sized groups, those with more and those with less growth than the median. Then the differences in advanced technology adoption of the two groups are compared using number of technologies calculated at the functional group level.

Establishments in the top half of the productivity growth distribution are found to be more likely to be using at least one advanced technology. This result extends across all functional groups. The difference is greatest for information and communication systems technologies, and process control technologies.

When growth in market share is used to divide the sample into two parts, similar results are found. The plants that experience the highest market-share growth also tend to be more likely to adopt advanced technologies from each of the groups. As with productivity growth, the largest differences are found for information and communication systems, and process control technologies.

Table 4. Relationship Between Performance Growth (1988-1997) and Advanced Technology Adoption (1998)

Advanced Technology Adoption	Performance Growth (1988-1997)			
	Relative Labour Productivity (I)		Market Share (II)	
	low	high	low	high
	Percentage of establishments using technologies			
• Processing	61	64	60	66
• Process control	55*	62*	53**	63**
• Quality control	38	44	38	44
• Inventory and distribution	39	44	38*	46*
• Information and communications systems	64**	72**	59***	77***
• Material handling	30*	37*	30	36
• Preprocessing	36	40	36	40
• Packaging	50	55	50	55
• Design and engineering	22	28	20***	30***

Note: *** Statistically significant difference at the 1% level; ** statistically significant difference at the 5% level. * Statistically significant difference at the 10% level.

6. *Multivariate Model*

6.1 Model

In this section, we use a multivariate framework to examine the connection between advanced technology use and two measures of the market performance of plants in the manufacturing sector.

Our model is conditioned by the following view of the world. In order to meet their objectives, firms have a wide array of strategies from which they choose. One of those strategies is what we refer to as an advanced technology strategy. But in order to implement this technology strategy, a set of complementary competencies like human resource strategies needs to be put in place. The successful use of technology then will depend on the existence of these complementary competencies, but also on the nature of the industry environment in which the firm finds itself. For example, firms in a more competitive environment are expected to behave differently from firms in a less competitive environment.

In the first instance then, we ask what firm and environmental characteristics are related to technology use.

Mathematically this can be expressed as:

$$1)\quad T_{it} = f(C_{it}, A_{it}, I_{it})$$

The technological capabilities of the firm are hypothesized to be related to certain intrinsic characteristics of the firm such as foreign ownership, to the activities in which the firm is engaged such as innovation, and to the competitive environment in which it is placed. The variable T_{it} measures the technological capabilities of firm i in period t, that is, the extent to which they have adopted advanced technologies. The variable C_{it} captures intrinsic firm characteristics, such as size and foreign ownership; A_{it} captures firm activities (innovation), while I_{it} measures industry-level characteristics (competitiveness).

In the second equation, we examine the factors related to productivity growth. We focus first in the whether plants with higher productivity growth are those using advanced technologies. But we are careful to avoid being biased towards technological determinism. Other characteristics of a firm may also influence productivity growth. In particular, some of the same characteristics that influenced technological choice may have an additional impact on productivity growth. For example, foreign ownership may not only affect whether more advanced manufacturing technologies are used, but also how effective the technologies are in terms of generating productivity growth.

Mathematically, the productivity growth equation may be expressed as:

$$2)\quad \Delta PROD_{i:t-\tau,t} = f(T_{it}, C_{it}, A_{it}, I_{it})$$

where $\Delta PROD_{i:t-\tau,t}$ is a measure of firm productivity growth by firm i over the period $t-\tau$ to t.

We relate performance over a period (1988-1997) to advanced technology use at the end of the period (1998). As such, we are postulating that performance over any period is posited to be a function of both advanced technology use at the beginning of the period and changes during the period.

When advanced technology use at the beginning of the period ($T_{t-\tau}$) plus any changes in use during the period ($\Delta T_{t-\tau, t}$) is substituted for advanced technology use at the end of the period (T_t), equation 2 can be rewritten:

$$3)\quad \Delta PROD_{i:t-\tau,t} = f\,(T_{t-\tau} + \Delta T_{t-\tau,t},\, C_{it},\, A_{it},\, I_{it})^{6}$$

We examine the relationship between productivity growth over the period 1988 to 1997 and advanced technology use at the end of the period because there is a learning process involved with the introduction and use of advanced technology. Changes in labour productivity resulting from advanced technology adoption are, therefore, expected to occur with a lag as plant managers learn how to use them in the most effective fashion. Since benefits or gains from the adoption of advanced technology are not realized immediately, there is a lagged effect of advanced technology use on performance and productivity growth in any period will depend upon technology use at the beginning of the period. We also expect that increases in advanced technology use during the period will affect relative performance over the period.

It may be the case that productivity growth and advanced technology use are endogenous variables, that is, they are each correlated with the error term. The degree to which this is true will depend on the lag structure inherent in the effect of technology use on performance. If the effects of technology use on firm performance have a relatively long lagged effect, then performance during a period will be mostly a function of technology use at the beginning of the period, and less a function of additions of technology during the period. Moreover, there may a lag between improvements in firm performance and subsequent additions to the machinery and equipment purchases that imbed advanced technology within them.

We examine the issue of possible endogeneity using the Hausman (1978) test, and reject the existence of simultaneity between productivity growth and technology use. As a result we employ ordinary least-squares regression techniques for the growth in productivity equation.

We also expect the growth in superior relative labour productivity will be reflected in higher growth in market share. As firms improve their relative productivity, this superior performance can be reflected in either price reductions or quality improvements. In either case, market share should improve. In addition to the impact of productivity growth on market-share growth, we hypothesize that other plant, firm and environmental characteristics may affect market-share growth.

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[6] The estimated coefficient from such an equation will be a weighted average of the coefficients that are attached to each of $Tech_{t-\tau}$ and $\Delta Tech_{t-\tau,t}$

Mathematically this may be expressed as:

$$4)\quad \Delta MKSHAR_{i:t-\tau,t} = f(\Delta PROD_{i:t-\tau,t}, C_i, A_i, I_i)$$

where $\Delta MKSHAR_{i:t-\tau,t}$ is the growth of market share of firm *i* over the period t-τ to t.

In this formulation, we see productivity growth driving market-share growth. While there may be a feedback effect from market-share growth to productivity growth (for example, that runs from market-share growth to increased profitability to increases in the purchases of technology), lags in this process make simultaneity unlikely. We examined the existence of this possibility by running two-stage least squares regressions for both equations two and four. When market share was included in the productivity growth equation, it was found to be insignificant[7] and corrections for endogenous productivity growth in equation four had no significant effect on the parameter estimates produced by ordinary least squares. We therefore report the results of the latter technique here.

Finally, it should be noted that both equations two and four are in their first-difference form because we are naturally interested in the growth of performance over time. By taking first differences, we coincidentally remove the problem of fixed effects, if they should happen to remain unchanged over time. But since they may not, we may still have a specification problem in both equations. Our inclusion of a large number of characteristics and activities of the firm in both equations 2 and 4 partially serves the additional function of correcting for the remaining problem of changing fixed effects.

6.1.1 Technology Use

On the basis of previous work (Baldwin, Diverty and Sabourin, 1995; Baldwin and Johnson, 1998; Baldwin, Sabourin and West, 1999) we posit technology use to be a function of a number of firm characteristics and industry characteristics.

Plant Characteristics

Plant size is included to capture several factors. First, large plants are likely to have more functions within them and therefore a higher probability of needing more advanced technologies. Second, large plants tend to invest more per dollar of sales in new equipment and capital are therefore more likely to spend part of their investment on advanced technologies. Third, larger plants are also more likely to have the superior financial and informational capabilities needed to ingest new advanced technologies. Employment data are used to measure size.

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[7] We note that we do not rule out the possibility of simultaneity. But the data used herein do not allow us to discern its impact. Part of the reason for the insignificance of market-share growth in the relative productivity growth equation using the two-stage approach is the low explanatory power of the equation that predicts market-share growth. Market-share growth is a stochastic process and is difficult to predict in the best of circumstances. Our choice then of the methodology adopted here is as much a result of our priors on the nature of the lag process as a result of definitive statistical tests on endogeneity.

Nationality of control of an establishment is included since multinational firms are seen to play an important role in the global diffusion of advanced technologies (Caves, 1982). The advantages of multinational enterprises are typically related to their size, expertise and financial resources. Nationality of control is captured by a binary variable that takes a value of one if the establishment is foreign controlled, and a value of zero if the establishment is domestically controlled.

Size is included for several reasons. It is often used as a proxy for scale effects. But it is also a proxy for differences in the internal capabilities of firms. Competencies of firms are rarely included in economic studies of the innovation process,[8] despite the fact that firms build up sets of competencies that are important for their overall growth and success. Baldwin and Johnson (1998) concluded in their study of small and medium sized businesses that the more innovative firms placed more emphasis on marketing, finance, production and human resource competencies than less-innovative firms. Technologically advanced firms are among the most innovative and, therefore, might be expected to build up these types of competencies in order to incorporate new technologies into the production process.

Whether a firm will be able to adopt new advanced technology should depend on whether a firm has developed a number of specialized competencies—relating to organizational structure, culture, and the capabilities of employees. To construct a set of measures that capture a variety of competencies that we have shown elsewhere to be related to whether a firm is capable of innovation (Baldwin and Johnson, 1998), we use a question on the food-processing survey that asks respondents to rate the importance of a set of factors, ranging from management to marketing to human resource strategies. Firms rank the importance they gave to various marketing, technology, production, management and human resource strategies on a 5-point Likert scale, ranging from 1 (low importance) to 5 (high importance).

Three competency variables are constructed that are based on the firms' responses to this set of questions. Responses to three questions are used to construct a *market strategy* variable. The questions measure the importance to the firm of introducing new products in present markets, introducing current products in new markets, and introducing new products in new markets. Similarly, a *technology strategy* variable is constructed using the responses to three other questions—the importance of using technology developed by others, of developing new technology, and of improving existing technology. Finally, *management and human resource strategies* were combined into a single category. Six questions were used to construct this variable. They measure the importance to the firm of continuously improving quality, of introducing innovative organizational structure, of using information technology, of continuously training staff, of introducing innovative compensation packages, and of recruiting skilled workers.

The scores given to the strategy variables by a firm represent underlying competencies in the firm. We use factor analysis to represent these underlying competencies.[9] Two factors were constructed and used for each of the three competency variables (see Appendix C).

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[8] For an exception, see Baldwin and Hanel (2003).

[9] The factors were derived using principal factor analysis.

Firm Activities

Also driving the need for advanced technologies are certain activities in which a firm may be engaged. For example, establishments employ a variety of business and engineering practices which require advanced technologies if they are to be effective. Some, such as hazard analysis critical points (HACCP) and food safety enhancement program (FSEP), are aimed at enhancing the quality of the products produced by the firm. Others are used to manage the materials handled by the firm. Materials requirement planning and just-in-time inventory are two examples of this type of practice. A third set includes techniques geared to increasing the speed, efficiency and effectiveness of product and process development. Examples include rapid prototyping and concurrent engineering. Each of these activities requires or is facilitated by the use of advanced technologies.

Previous studies (Gordon and Wiseman, 1995; Baldwin and Sabourin, 2000) find that the adoption of such practices, particularly those devoted to product and process development, provide firms with a comparative advantage and an increased likelihood of being innovative. Use of advanced engineering and business practices has been found to be an important complement to the use of advanced technologies (Baldwin and Sabourin, 2000).

Three binary variables are constructed to capture the effects of using advanced practices. The first binary variable captures whether a plant uses practices aimed at quality enhancement; the second, whether it uses practices targeted for materials management; the third whether it uses practices aimed at product and process development.

Each of the three binary variables takes a value of one if a firm uses any of the practices listed within the group, and a value of zero otherwise.

Eight practices are listed on the survey questionnaire relating to quality enhancement—continuous quality improvement, benchmarking, acceptance sampling, certification of suppliers, good manufacturing practices, hazard analysis critical control points, food safety enhancement program and plant quality certification.

Seven practices pertain to materials management—materials requirement planning, manufacturing resource planning, process changeover time reduction, just-in-time inventory control, electronic work order management, electronic data interchange and distribution resource planning.

Nine practices are listed for product and process development—rapid prototyping, quality function deployment, cross-functional design teams, concurrent engineering, computer-aided design, continuous improvement, process benchmarking, process simulation and process value-added analysis.

Innovative firms are more likely to use advanced technologies because the latter are often associated with the introduction of either new products or new processes (Baldwin and Sabourin, 2001). The innovative stance of the firm is measured in two ways in this study—first, with a

variable that captures the extent to which innovations are being produced; second, with a variable that captures whether R&D is being performed.

Innovation characteristics are captured using a taxonomy that classifies firms into one of five mutually exclusive types—process specialized innovators, product specialized innovators, combined innovators, comprehensive innovators and non-innovators. Process specialized innovators are innovators that specialize in process innovations. Product specialized innovators are innovators that primarily produce product innovations. Combined innovators are establishments that introduce some combination of process innovation and product innovation, either with or without associated process innovation. And comprehensive innovators are innovators that introduce innovations of all types. Five binary variables were constructed to capture the innovator type.

To capture related aspects of an innovation program, a binary variable is also included indicating if a plant reported that it performs R&D. Contrary to the innovation variables that capture whether there any outputs from the innovation process, this variables captures inputs to the innovation process. A firm may not have any innovative outputs despite having devoted resources to R&D. For this reason, both variables are used here.

Industrial Environment

Technology use might be related to the competitive environment faced by a firm. Firms involved in fiercely competitive markets might be expected to have more pressures placed upon them to adopt technologies.

Competition is measured in two ways in this study. First, it is measured by numbers of competitors. Plants are assigned to one of three competition groups according to the number of competitors they face—five or fewer, six to 20, or more than 20 competitors. Three binary variables are used to capture these competitive categories.

An alternative approach is also pursued. Plant managers are asked to evaluate the importance to their industry of a set of factors that overall determine the competitive environment faced by their plant—whether competition from imports was important; whether new competitors posed a constant threat; whether production technology changed rapidly; whether consumer demand was hard to predict; whether competitors were unpredictable; whether products quickly became obsolete; whether competitors could easily substitute among suppliers; and whether customers or suppliers could easily become competitors.

Scores on these categories are summed across all eight statements. High aggregate scores suggest a highly competitive environment, while low aggregate scores suggest just the opposite.

Finally, binary variables are included to control for industry effects. Seven sub-industries of food processing were used—bakery, cereal, dairy, fruit and vegetables, fish, meat, and other food products.

6.1.2 Productivity Growth

Firm Characteristics

Productivity growth is hypothesized to be a function of the technological profile of the industry. We capture advanced technology use in two ways. In the first case, we employ a measure of intensity of use. In the second case, we employ a measure of the different combinations of technologies being used.

To measure intensity of use, we employ the number of technologies an establishment has adopted. As there are 60 advanced technologies listed on the survey, this is a variable ranging from zero to 60. To measure different combinations of advanced technology use, we employ principal component analysis, which was discussed in Section 4.

Productivity growth is also likely to be a function of changes in capital intensity. Since advanced technology use probably increases with increases in the capital intensity of a plant, our measure of technology use may simply capture capital intensity. While this is of intrinsic interest, we would also like to know whether advanced technology use still matters after capital intensity has been taken into account. For then it is not so much the amount of capital employed as the type that matters. To correct for capital intensity, the increase in a plant's relative profitability (its profit/sales ratio) is also included—since this measure of profitability is closely correlated with capital intensity on average.

Productivity growth is also postulated to depend on productivity in the initial period in order to allow for regression-to-the-mean. Previous work (Baldwin, 1995; Baldwin and Sabourin, 2001) and the tables presented in the first section of this paper have reported that plants tend to regress to the mean over the period.

Finally, we include the same set of firm characteristics—nationality, competencies, innovation intensity, and competitive environment—that were used in the technology use equation. Our use of this variable allows us to test whether productivity growth depends not just on technology but also on a wider range of firm characteristics.

Nationality is included since previous work has found that labour productivity growth in foreign-controlled plants has been higher than in the domestic sector in the 1980s and 1990s (Baldwin and Dhaliwal, 2001).

Competencies are included to test whether the underlying characteristics of firms that are related to technology use also affect the amount of productivity growth that is generated. The inclusion of these variables not only provides us with insight into the types of competencies that are associated with productivity growth, but it also helps to reduce the fixed-effects econometric problem. The econometrics literature has spent considerable effort worrying that equations such as the ones we are trying to estimate will yield biased estimates of the parameters attached to the independent variables if there are omitted fixed effects at the plant level that are correlated with the included variables. Previous studies have found advanced technology adoption is correlated

with R&D activity, innovation, and the use of advanced business and engineering practices. Because of this, a regression that includes advanced technology use, but not any of the firm characteristic and activity variables, risks attributing any effect due to intrinsic competencies and activities to the adoption of advanced technology. The correlation between technology use and productivity growth may simply reflect the fact that superior firms, in addition to making more use of advanced technologies, do a host of other things that influence growth as well (see McGuckin et al., 1998). The inclusion of several measures of firm characteristics and activities hopefully serves to alleviate this problem.

Previous studies (Lichtenberg and Siegel, 1991; Hall and Mairesse, 1995; Dilling-Hansen et al., 1999) indicate that R&D has a positive effect on productivity. In this study, we are also interested in knowing whether R&D activity and innovation affect productivity performance after the technology mix has been taken into account.

Productivity growth might also be related to the competitive environment faced by a firm. Firms involved in fiercely competitive markets might be expected to have more gains in productivity than those firms in a much less competitive environment. For this reason, our measures of competitive environment are included.

6.1.3 Market-share Growth

The third model examines the correlates of growth in market share. Growth in market share is postulated to depend on factors that give a firm an advantage over its competitors.

Growth in market share is posited to be a function of both the advantages in labour productivity experienced at the beginning of the period and its growth over the period. Initial period productivity is taken to represent relative advantage at the beginning of the period, while growth in productivity captures changes in this advantage that take place during the period.

In our formulation, growth in relative labour productivity is a proxy for a host of factors that are related to technical efficiency, changes in capital intensity, and other competencies in a firm—from management capabilities to human resource strategies such as training.

But we also explicitly include certain measures of a firm's competencies. Measures relating to the importance attributed by firms to their market strategy, their technological development strategy, their management, and their human resources strategy are included in the market-share equation. This allows us test whether these competencies affect market-share growth independent of their indirect effect on productivity growth through technology use.

Although we already included advanced technology use in the labour productivity equation, we also include it in the market-share equation to test whether there is an effect of advanced technology on market-share growth that is separate from its effect on the growth in relative labour productivity. Advanced technology use not only allows relative cost gains that are reflected in lower prices, but it also improves the flexibility in the production process and the quality of products produced (Baldwin, Sabourin and Rafiquzzaman, 1996; Baldwin, Sabourin,

and West, 1999). As such, it might be expected to have an effect on growth in market share independent of its effect on measured labour productivity.

The other variables that were included in the market-share equation are essentially the same as those used in the relative productivity growth model, with the addition of opening-period market share to allow for regression-to-the-mean.

6.1.4 Model Specification

Three separate equations are estimated. The first examines technology use. The second equation estimates the correlates of productivity growth and the second the correlates of market-share growth. The regressions that were estimated are:

1) $\text{TECH} = \alpha_0 + \alpha_1 * \text{SIZE88} + \alpha_2 * \text{FOREIGN} + \alpha_3 * \text{R\&D} + \alpha_4 * \text{COMPET} + \alpha_5 * \text{PRACTICES} + \alpha_6 * \text{COMPENV} + \alpha_7 * \text{STRATEGIES} + \alpha_8 * \text{INNOV} + \alpha_9 * \text{INDUSTRY}$

2) $\text{PRODGRTH} = \beta_0 + \beta_1 * \text{TECH} + \beta_2 * \text{SIZE88} + \beta_3 * \text{FOREIGN} + \beta_4 * \Delta\text{CAPINT} + \beta_5 * \text{LABPROD88} + \beta_6 * \text{R\&D} + \beta_7 * \text{COMPET} + \beta_8 * \text{PRACTICES} + \beta_9 * \text{COMPENV} + \beta_{10} * \text{STRATEGIES} + \beta_{11} * \text{INNOV} + \beta_{12} * \text{INDUSTRY}$

3) $\text{SHARGRTH} = \gamma_0 + \gamma_1 * \text{TECH} + \gamma_2 * \text{SIZE88} + \gamma_3 * \text{FOREIGN} + \gamma_4 * \text{LABPROD88} + \gamma_5 * \Delta\text{LABPROD} + \gamma_6 * \text{MKTSHR88} + \gamma_7 * \text{R\&D} + \gamma_8 * \text{COMPET} + \gamma_9 * \text{PRACTICES} + \gamma_{10} * \text{COMPENV} + \gamma_{11} \text{STRATEGIES} + \gamma_{12} * \text{INNOV} + \gamma_{13} * \text{INDUSTRY}$

where *TECH* measures the number of advanced technologies used by the establishment.
PRODGRTH measures the growth in relative labour productivity of a plant.
SHARGRTH measures the growth in market share of a plant.
SIZE88 measures opening-period employment size of the plant.
FOREIGN captures whether or not an establishment is foreign owned.
ΔCAPINT captures changes in the capital intensity of a plant through changes in profitability.
ΔLABPROD measures changes in relative labour productivity over time.
LABPROD88 measures opening-period labour productivity levels.
MKTSHR88 measures opening-period market share.
R&D captures whether or not an establishment is an R&D performer.
COMPET measures the number of competitors a firm faces.
PRACTICES measures the use of advanced business and engineering practices.
COMPENV measures the intensity of competition within an industry.
STRATEGIES measures the competencies of a firm.
INNOV measures the innovative characteristics of a firm.
INDUSTRY captures industry effects.

6.2 Empirical Results

Summary statistics for the dependent and independent variables for the OLS regressions, using productivity growth and market-share growth as the dependent variables, are provided in Table 5. For example, the mean number of advanced technologies (TECH) adopted by food processing plants in 1998 was 7.4, while food-processing plants had a mean size of 72 employees and 61% of these plants were engaged in R&D activity.

Table 5. Summary Statistics for Dependent and Independent Regression Variables (Establishment Weighted)

Variable	Description	Mean	Standard Deviation
1. Dependent Variables			
PRODGRTH	Growth in relative labour productivity	0.022	0.045
SHARGRTH	Growth in market share	0.001	0.003
2. Technology Use			
TECH	Number of technologies	7.38	0.26
3.Firm Characteristics			
SIZE88	Plant employment	71.78	4.49
FOREIGN	Foreign owned	0.13	0.01
R&D	R&D performer	0.61	0.02
MKTSHR88	Initial market share	0.008	0.001
LABPROD88	Initial relative labour productivity	0.89	0.03
CAPINT	Capital intensity	0.42	0.36
4.Industry Characteristics			
BAKERY	Bakery		
CEREAL	Cereal	0.17	0.02
DAIRY	Dairy	0.12	0.01
FISH	Fish	0.14	0.02
FRUIT AND VEGETABLES	Fruit and vegetables	0.07	0.01
MEAT	Meat	0.19	0.02
OTHER	Other food products	0.19	0.02

The results of the OLS regression that measures technology use by numbers of technologies adopted are presented in Table 6. The results for productivity growth and market-share growth are presented in Tables 7, 8 and 10. Table 7 contains a reduced set of variables, while Tables 8 and 10 use an expanded set of variables. Interpretation of the principal component results for the technology variables are provided in Tables 9 and 11 for the productivity growth and market-share growth equations, respectively. All regressions are weighted and are estimated against an excluded plant that is Canadian-owned, does not perform R&D, and is in the bakery industry.

6.2.1 Technology Use

The number of technologies that are used is a positive function of both size and of nationality. As has been found repeatedly (Baldwin, Diverty and Sabourin, 1995; Baldwin and Sabourin, 1995; and Baldwin, Sabourin and West, 1999), larger plants use more advanced technologies than small plants. We also confirm the finding that foreign plants are more likely to use more advanced technologies, even after for controlling for their larger plant size (Baldwin, Rama and Sabourin, 1999).

Table 6. Ordinary Least Squares Regressions for Technology Use (Establishment Weighted)

	MODEL 1	MODEL 2	MODEL 3
Intercept	-3.80***	-4.21***	-1.72*
Plant Size			
Employment Size-1988	0.017***	0.016***	0.014***
Nationality of Control			
Foreign	1.81***	1.54**	1.22*
Innovation			
Process specialized	.	1.92**	1.32
Product specialized	.	0.96	0.77
Combined	.	2.67***	2.29***
Comprehensive	.	3.83***	3.38***
R&D			
Ongoing R&D performer	1.09**	0.45	0.11
Competition			
6-20 competitors	1.06**	0.71	0.49
Over 20 competitors	1.12**	0.96*	0.73
Business Practices			
Product quality	1.94***	1.42*	0.37
Management	2.54***	2.52***	2.15***
Product/Process development	3.24***	2.78***	2.54***
Firm Strategies			
Technology			
- factor 1	.	.	0.78***
- factor 2	.	.	0.16
Marketing			
- factor 1	.	.	-0.10
- factor 2	.	.	-0.18
Management/Human Resources			
- factor 1	.	.	0.45*
- factor 2	.	.	-0.38**
Industry			
Cereal	1.53**	1.92***	1.71***
Dairy	4.43***	4.31***	4.10***
Fish	1.45*	1.46*	1.22
Fruit & vegetables	2.12***	2.34***	2.44***
Meat	3.17***	3.19***	3.11***
Other	2.30***	1.98***	1.83***
Summary Statistics			
N	538	538	538
F(degrees of freedom)	F(14,523) = 26.90	F(18,519) = 23.27	F(24,513) = 19.07
R^2	0.38	0.43	0.46

Note: *** statistically significant at the 1% level; ** statistically significant at the 5% level; * statistically significant at the 10% level

Firms that are more innovative are more likely to use advanced technologies, which confirms the findings of the *1993 Survey of Innovation and Advanced Technology* that many firms that introduce innovations adopt new advanced manufacturing technologies at the same time (Baldwin and Hanel, 2003). Performing R&D is positively related to technology use, though this variable becomes insignificant once the innovation variables are included. The categories of innovation that are positively related to advanced technology use all involve some aspect of process innovation.

Two of the groups of business practices are positively and significantly related to advanced technology use, after controlling for firm competencies. Certain activities—managing materials and product/process development—drive the adoption of advanced technologies. Product quality practices are positively correlated to technology use but their significance is greatly reduced when innovation is included.

Most of the underlying characteristics are found to be insignificant once the other controls are included. Not surprisingly, adopting a technological bent (developing new technologies and improving existing technologies) matters. But so does the second factor under the management and human resource group. The results show that using innovative compensation packages, information technology and innovative organizational structures is associated with the use of advanced technologies.

6.2.2 Growth in Labour Productivity

Growth in relative labour productivity is positively and significantly related to advanced technology use (column 1, Table 7). During the nineties, more intensive use of advanced technology is associated with higher productivity growth.

The coefficient on the starting-period relative productivity variable is negative and highly significant. There is regression-to-the-mean in relative productivity. Plants that started the period with a high relative labour productivity saw their relative labour productivity decline. Equivalently, those plants that were below average in terms of relative labour productivity at the start of the period saw their productivity increase relative to their compatriots.

There is a large, significant effect of the growth in capital intensity on the growth in relative labour productivity that is consistent with the literature.

Neither nationality of ownership nor plant size is significantly related to relative labour productivity growth throughout this period. Both coefficients are positive but not significant.

Neither R&D performance nor industry is a significant determinant of a plant's relative productivity growth. This suggests that the fixed effects that these variables capture do not bias the estimated impact of technology on productivity growth.

6.2.3 Growth in Market Share

Growth in labour productivity over the period is a positive, and highly significant, factor contributing to market-share growth (column 2, Table 7). Labour productivity at the start of the period, on the other hand, does not significantly contribute to the growth in market share.

Even after taking into account the effects of relative productivity growth on market share, there is an additional impact of advanced technology use on the growth in market share.

Table 7. Regressions for Productivity and Market-share Growth (1988 to 1997)—(Establishment Weighted)

	Δ Relative Labour Productivity	Δ Market Share
Intercept	0.215*	0.0006
Advanced Technology Use		
Number of technologies	0.014**	0.0001*
Plant Size		
Employment Size-1988	0.0005	8e-6
Nationality of Control		
Foreign	0.092	0.002
Capital Intensity		
Profitability change 1988-1997	0.020***	---
Initial Labour Productivity		
Relative Labour Productivity — 1988	-0.442***	-0.0003
Labour Productivity Growth		
Relative Labour Productivity Growth	---	0.002***
Initial Market Share		
Market Share — 1988	---	0.013
R&D		
Ongoing R&D performer	-0.128	-0.0008
Industry		
Cereal	0.131	-0.0001
Dairy	0.255	-0.0005
Fish	0.033	-0.0002
Fruit & Vegetables	0.059	0.0008
Meat	0.211	-0.0001
Other	0.132	-0.0008
Summary Statistics		
N	524	537
F(degrees of freedom)	(12,511) = 4.61	(13,523) = 1.94
R^2	0.15	0.07

Note: *** statistically significant at the 1% level; ** statistically significant at the 5% level; * statistically significant at the 10% level

The coefficients for both size and foreign ownership are positive, but neither is significant. R&D and growth in market share are negatively related; but, like the coefficients on size and ownership, this result is not statistically significant.

6.2.4 Principal Component Analysis

Principal component analysis allows us to extend our investigation as to the types of advanced technologies that are associated with growth. The results of the OLS regressions using principal components to capture advanced technology effects are presented in Table 8, while the interpretation of the significant principal components are provided in Table 9.

These new results also contain an expanded list of explanatory variables that include more innovation, business practice and firm competency variables so as to test for the importance of underlying fixed effects.

6.2.4.1 Relative Productivity

These results indicate that our conclusions are robust to the way in which advanced technology use is measured. Whether measured by the number of technologies adopted or by using principal components, the significance levels for the other explanatory variables in the system remain virtually unchanged. More importantly, the characteristics, innovation and competitive environment variables virtually never have an additional impact on relative productivity, outside of their impact on technology use. The one exception is management/human resource factor 2.

Six principal technology components are significantly related to productivity growth (Tables 8 and 9). Establishments that emphasize the joint use of advanced information and communications systems, process control, and packaging technologies are more likely to enjoy productivity growth, according to the results of the first principal component (Tech1). ICT systems then are critical to processing control technologies.

Plants, for which the use of advanced pre-processing and process control technologies together are important, and where advanced packaging and thermal preservation together are not (Tech4), are also more likely to undergo growth in productivity. Process control technology includes the likes of programmable logic controllers, computerized process control and sensor-based inspection equipment. Pre-processing technologies are technologies used for raw product quality enhancement and raw product quality assessment, including bran removal, micro separation and electronic grading. In an industry concerned with product regulations governing food quality and safety, the use of advanced technologies dedicated to minimizing spoilage and wastage can lead to gains in productivity. Recalling our discussion of principal components by industry (Appendix Table B2), we might expect this to be most important for plants in the meat and dairy industry.

Principal component seven (Tech7) is also highly significant. It is negatively related to productivity growth, which means that plants that emphasize advanced separation processing techniques, sophisticated testing techniques and the use of advanced packaging methods, while de-emphasizing information and communications systems, thermal preservation heating and design and engineering, are more likely to be associated with productivity growth.

Three other of the top fifteen principal components (Tech5, Tech6 and Tech15) are significant at the 10% level. All three are negatively related to productivity growth. In the case of Tech6, this means that plants favouring information and communications technologies and rapid testing techniques, and not statistical process control, machine vision, product handling and high-pressure sterilization, are more likely to achieve growth in productivity.

In summary, information and communication technologies have been positively linked to productivity growth through a number of different components. ICT is important, but in combination with other technologies. Adoption of technologies like local and wide area networks, and inter-company computer networks are positively associated with higher productivity growth throughout the 1990s. Transfer of information both within an organization and between organizations is closely associated with growth in productivity, lending support to the view that the adoption of ICTs is important to productivity growth.

As before, growth in capital intensity has a large and highly significant effect on productivity growth. Regression-to-the-mean is also present since the coefficient on the starting-period productivity variable is negative and highly significant.

Outside of R&D and certain firm competencies, few of the firm characteristics variables are significant. Size of establishment and whether a plant has introduced innovations are positively, although not significantly, related to productivity growth. The coefficient attached to country of control is negative, but also not significant. And whether an establishment adopts advanced engineering and business practices is also not significant.

R&D activity has a negative and weakly significant impact on productivity growth, although this relationship is no longer statistically significant after controlling for differences in firm competencies as measured by technological, marketing, management and human resources capabilities of the firm.

Of the firm competencies, only management and human resources have a significant effect. The second factor for this competency is positively, and significantly, related to productivity growth. The second factor loads positively on three characteristics and negatively on three other characteristics (Appendix C). The three factors that are positively loaded are continuously improving quality, continuously training staff and recruiting skilled workers. The negative loadings are for introducing innovative organizational structure, using information technology and introducing innovative compensation packages. This factor describing a firm's tendency to concentrate on creating and maintaining a skilled workforce, through both training and recruitment, and to improve the quality of the products offered by the firm. Food processing plants that exhibited this competency were less likely to have adopted advanced technologies but were more likely to have enjoyed productivity growth if they had done so during the nineties. These practices served as substitutes for an advanced technology strategy in the food-processing sector.

The competitive environment, measured in two ways in this study, is not significantly related to the productivity growth of establishments in the food processing industry, at least not throughout the 1990s. Neither the number of competitors a firm faces, nor the intensity of competition within an industry as measured by an extensive set of environmental characteristics has a statistically significant effect.

6.2.4.2 Growth in Market Share

In the market-share growth regression, the first principal technology component is once again significant. An emphasis on advanced information and communications systems, process control and packaging technologies is positively related to market-share growth.

Plants that manage to incorporate advanced information and communication systems, process control technologies, and even advanced packaging technologies tended to grow in terms of their relative productivity during the past decade. In turn, growth in productivity from adopting these technologies leads to growth in market share. The fact that this principal component is significant even after controlling for growth in productivity indicates there exists an additional effect, over and above that received from productivity growth.

Table 8. OLS Principal Components Regressions for Productivity Growth (1988-1997) (Establishment Weighted)

	Model 1	Model 2	Model 3	Model 4
Intercept	0.260	0.214	0.213	0.154
Advanced Technology Use				
Tech1	0.034**	0.029*	0.039**	0.033*
Tech2	-0.009	-0.008	-0.008	-0.006
Tech3	-0.072	-0.071	-0.074	-0.073
Tech4	0.082**	0.082**	0.081**	0.081**
Tech5	-0.053*	-0.054	-0.057*	-0.058*
Tech6	-0.046*	-0.043	-0.056**	-0.053*
Tech7	-0.074***	-0.073***	-0.070***	-0.069***
Tech8	-0.025	-0.024	-0.028	-0.026
Tech9	-0.019	-0.016	-0.024	-0.020
Tech10	0.009	0.011	0.006	0.008
Tech11	-0.006	-0.006	-0.005	-0.005
Tech12	0.013	0.015	0.006	0.008
Tech13	-0.007	-0.006	-0.005	-0.004
Tech14	-0.018	-0.015	-0.019	-0.016
Tech15	-0.074*	-0.071*	-0.076*	-0.072*
Plant Size				
Employment Size-1988	0.0004	0.0004	0.0005	0.0005
Nationality of Control				
Foreign	-0.025	-0.020	-0.028	-0.025
Capital Intensity				
Profitability change (88-97)	0.019***	0.019***	0.019***	0.019***
Initial Labour Productivity				
Relative Productivity (1988)	-0.483***	-0.486***	-0.476***	-0.478***
R&D				
Ongoing R&D performer	-0.142*	-0.168*	-0.129	-0.153*
Competition				
6-20 competitors	-0.024	-0.038	0.004	-0.013
Over 20 competitors	-0.021	-0.030	0.001	-0.008
Business Practices				
Product quality	0.147	0.137	0.122	0.110
Management	0.051	0.049	0.077	0.079
Product/Process development	-0.001	-0.012	-0.010	-0.018
Competitive Environment				
Industry environment	0.00008	-0.00009	-0.00006	0.0001
Innovation				
Process specialized	---	0.126	---	0.136
Product specialized	---	0.103	---	0.088
Combined	---	0.083	---	0.095
Comprehensive	---	0.141	---	0.150
Firm Strategies				
Technology				
- factor 1	---	---	0.007	0.007
- factor 2	---	---	-0.032	-0.024
Marketing				
- factor 1	---	---	-0.006	-0.007
- factor 2	---	---	-0.019	-0.020
Management/Human Resources				
- factor 1	---	---	-0.033	-0.038
- factor 2	---	---	0.075*	0.077*
Industry				
Cereal	0.048	0.066	0.068	0.087
Dairy	0.229	0.240	0.261	0.270
Fish	0.104	0.118	0.120	0.132
Fruit & vegetables	0.040	0.051	0.073	0.084
Meat	0.285	0.298	0.299	0.310
Other	0.092	0.089	0.107	0.102
Summary Statistics				
N	524	524	524	524
F(degrees of freedom)	F(32,491) = 4.09	F(36,487) = 3.66	F(38,485) = 3.66	F(42,481) = 3.31
R^2	0.20	0.20	0.20	0.21

Note: *** statistically significant at the 1% level; ** statistically significant at the 5% level; * statistically significant at the 10% level.

Table 9. Interpretation of Statistically Significant Technology Principal Components for Productivity Growth Regression

Principal Component	Sign of coefficient	Emphasizes	Downplays
Tech1	positive	Process control; information and communications; packaging; rapid testing; CAD/CAE	----------
Tech4	positive	Pre-processing (separation, testing, grading); process control; DNA probes	Bar coding; modified atmosphere and laminates (packaging); aseptic processing and flexible packages (thermal preservation); monoclonal antibodies (quality control)
Tech5	negative	Quality control (excl. simulation modeling); bio-ingredients for processing; rapid testing; digital CAD; pre-processing	Inventory and distribution; machine vision; use of the internet
Tech6	negative	High pressure sterilization; product handling; statistical process control; machine vision; robots; digital CAD	Information and communications; collagen probe (pre-processing); rapid testing
Tech7	negative	Information and communications; thermal preservation heating; simulation modeling (quality control); design and engineering (excluding CAD/CAE)	Separation techniques; sensor-based testing; rapid testing; modified atmosphere, laminates, and multi-layer materials (packaging)
Tech15	negative	Thermal preservation; pre-processing separation and grading; and automated laboratory testing	Chemical antimicrobials; DNA probes; bio-ingredients; chromotography; and defect sorting

The sign of the coefficient on the second principal component indicates that establishments that adopt both advanced preservation and advanced packaging technologies, and tend not to adopt advanced processing technologies, are more likely to achieve growth in market share. Similarly, the sign on the fifteenth component indicates that the adoption of advanced thermal technologies, advanced non-thermal preservation technologies and advanced separation and water removal technologies, but not advanced quality control technologies, is associated with increasing market share.

It is noteworthy that none of the additional strategic competency, business practices, innovation, or competitive environment variables has a significant direct impact on market share. They have a direct impact on technology use and technology use, in turn, affects productivity and productivity affects market-share growth. But they have no separate impact on the latter.

Table 10. OLS Principal Components Regressions for Market-share Growth (1988-1997) (Establishment Weighted)

	Model 1	Model 2	Model 3	Model 4
Intercept	0.002	0.002	0.003	0.002
Advanced Technology Use				
Tech1	0.0003*	0.0004*	0.0003*	0.0003*
Tech2	-0.0004**	-0.0005**	-0.0004**	-0.0005**
Tech3	-0.0002	-0.0002	-0.0002	-0.0002
Tech4	0.0007*	0.0007*	0.0007*	0.0007*
Tech5	0.00005	0.0001	0.00006	0.0001
Tech6	0.00001	-0.00004	0.00004	-0.00001
Tech7	0.00006	0.00004	0.00007	0.00005
Tech8	0.0003	0.0003	0.0003	0.0003
Tech9	-0.0002	-0.0002	-0.0002	-0.0002
Tech10	0.0005	0.0005	0.0005	0.0005
Tech11	-0.0007	-0.0007	-0.0007	-0.0007
Tech12	0.0005	0.0005	0.0005	0.0005
Tech13	0.0005	0.0005	0.0005*	0.0005
Tech14	-0.0002	-0.0002	-0.0002	-0.0002
Tech15	0.0008**	0.0008**	0.0008**	0.0008**
Plant Size				
Employment Size-1988	0.00001	0.00001	0.00001	0.00001
Nationality of Control				
Foreign	0.002	0.002	0.002	0.002
Initial Market Share				
Market Share (1988)	-0.00004	-0.0005	0.0002	-0.0002
Initial Labour Productivity				
Relative Productivity (1988)	-0.0006	-0.0006	-0.0007	-0.0006
Labour Productivity Growth				
Relative Productivity Growth	0.0014***	0.0014***	0.0014***	0.0014***
R&D				
Ongoing R&D performer	-0.0007	-0.0006	-0.0008	-0.0007
Competition				
6-20 competitors	0.0007	0.0009	0.0006	0.0008
Over 20 competitors	-0.0002	-0.0001	-0.0003	-0.0002
Business Practices				
Product quality	-0.0002	-0.0002	-0.0002	-0.0002
Management	-0.0006	-0.0004	-0.0006	-0.0004
Product/Process development	0.0002	0.0003	0.0003	0.0003
Competitive Environment				
Industry environment	-0.00001	0.000002	0.000009	0.000003
Innovation				
Process specialized	---	-0.0005	---	-0.0004
Product specialized	---	-0.0010	---	-0.0010
Combined	---	0.0003	---	0.0003
Comprehensive	---	-0.0008	---	-0.0008
Firm Strategies				
Technology				
- factor 1	---	---	0.0002	0.0002
- factor 2	---	---	0.0001	0.0001
Marketing				
- factor 1	---	---	0.0001	0.0001
- factor 2	---	---	-0.0001	-0.0001
Management/Human Resources				
- factor 1	---	---	-0.0001	-0.0002
- factor 2	---	---	-0.0001	-0.0001
Industry				
Cereal	-0.001	-0.001	-0.001	-0.001
Dairy	-0.0002	-0.0003	-0.0001	-0.0002
Fish	0.0001	-0.0001	0.00004	-0.0001
Fruit & vegetables	0.0006	0.0007	0.0006	0.0007
Meat	0.0008	0.0008	0.0009	0.0009
Other	-0.0010	-0.0009	-0.0009	-0.0009
Summary Statistics				
N	537	537	537	537
F(degrees of freedom)	F(33,503) = 1.43	F(37,499) = 1.28	F(39,497) = 1.32	F(43,493) = 1.20
R^2	0.11	0.11	0.11	0.11

Note: *** statistically significant at the 1% level; ** statistically significant at the 5% level; * statistically significant at the 10% level.

Table 11. Interpretation of Statistically Significant Technology Principal Components Market-share Regressions

Principal Component	Sign of coefficient	Emphasizes	Downplays
Tech1	positive	Process control; information and communications; packaging; rapid testing; CAD/CAE	----------
Tech2	negative	Processing technology, of all types	Robots; packaging machinery; statistical process control; CAD output
Tech 4	positive	Pre-processing (separation, testing, grading); process control; DNA probes	Bar coding; modified atmosphere and laminates (packaging); aseptic processing and flexible packages (thermal preservation); monoclonal antibodies (quality control)
Tech15	positive	Thermal preservation; pre-processing separation and grading; and automated laboratory testing	Chemical antimicrobials; DNA probes; bio-ingredients; chromotography; and defect sorting

6.2.5 Competitiveness

The previous three sections have studied the relationship between advanced technology use and actual measures of firm performance—labour productivity growth and market-share growth—that were derived from administrative files.

This section uses an alternate method to assess the importance of advanced technology use. The food-processing technology survey asks plant managers to assess the 'competitiveness' of their production technologies. Competitiveness, of course, involves a wide range of outcomes, only two of which fall under 'relative productivity growth' and 'market-share growth'. Nevertheless, these two characteristics should heavily influence 'competitiveness'.

Plant managers rate their production technologies against those of their competitors, both domestic and foreign, using a five-point Likert scale. Of interest in this study is the comparison between Canadian food processing establishments and their U.S. competitors. As Baldwin, Sabourin and West (1999) report, just slightly more than half of the establishments consider themselves to be less competitive than their U.S. counterparts.

Based on the results of this question, a binary dependent variable is constructed with a value of one if the plant's production technology was evaluated to be more competitive than that of its U.S. competitors, and a value of zero if it was less technologically competitive than that of its U.S. competitors. Those that rated their technology as the same as their U.S. counterparts were omitted from the analysis.

Table 12. Comparison of Productivity Growth, Market-share Growth and Competitiveness Regressions (Establishment Weighted)

	PRODUCTIVITY GROWTH (OLS)	MARKET-SHARE GROWTH (OLS)	COMPETITIVENESS (LOGIT)
Intercept	0.334	0.0014*	-0.051
Advanced Technology Use			
Tech1	0.034**	0.0003*	0.448***
Tech2	-0.009	-0.0004**	-0.423***
Tech3	-0.071	-0.0002	-0.285*
Tech4	0.081**	0.0007*	0.405*
Tech5	-0.055*	0.00005	0.141
Tech6	-0.041	0.000003	-0.411***
Tech7	-0.075***	0.00007	-0.044
Tech8	-0.024	0.0002	-0.150
Tech9	-0.026	-0.0002	-0.513**
Tech10	0.008	0.0005	-0.179
Tech11	-0.009	-0.0007	-0.257
Tech12	0.011	0.0005	-0.021
Tech13	-0.005	0.0005*	0.108
Tech14	-0.019	-0.0002	0.274
Tech15	-0.075*	0.0008**	-0.137
Plant Size			
Employment Size-1988	0.0004	0.00001	0.0015
Nationality of Control			
Foreign	0.024	0.002	0.173
Capital Intensity			
Profitability change (88-97)	0.018***	---	-0.020
Initial Labour Productivity			
Relative Productivity (1988)	-0.489***	-0.0006	-0.467**
Labour Productivity Growth			
Productivity Growth (1988-97)	---	0.0014***	---
Initial Market Share			
Market Share (1988)	---	0.0007	---
Industry			
Cereal	0.058	-0.001	0.282
Dairy	0.222	-0.0001	-0.470
Fish	0.117	0.0001	2.716***
Fruit & vegetables	0.008	0.0006	0.485
Meat	0.287	0.0010	0.822
Other	0.089	-0.0009	0.893
Summary Statistics			
N	524	537	252
F(degrees of freedom)	F(25,498) = 4.36	F(26,510) = 1.62	---
R^2	0.19	0.11	0.30
Wald Chi square	---	---	70.7

Note: *** statistically significant at the 1% level; ** statistically significant at the 5% level; * statistically significant at the 10% level.

Regression results comparing the three measures of performance—productivity growth, market-share growth and competitiveness—are presented in Table 12. The sign of several of the major principal components were the same in the competitiveness equation as in the relative productivity growth or in the market-share growth. The first four components have the same sign in the competitiveness regression as in both the productivity and market-share equation. They are more significant in the competitiveness equation than in the other two.

This confirms the findings of the previous section. Technology use is closely associated with firm performance, whether measured directly from the actual data on growth and productivity, or whether measured by the evaluation of plant managers as to their 'competitiveness'.

7. Conclusion

This paper is the third to examine the relationship between firm performance and advanced technology use. In two previous papers (Baldwin, Diverty and Sabourin, 1995; Baldwin and Sabourin, 2001), we find that manufacturing plants that managed to successfully incorporate advanced technologies saw their productivity grow more quickly and their market share increase. This paper replicates this finding for the food-processing sector, using a more detailed set of technologies.

The previous studies reported that it was information and communications technologies (ICTs) that were most closely associated with superior performance. This study finds the same. It provides strong evidence that the use of ICTs is associated with superior firm performance. Greater use of advanced information and communication technologies is associated with higher labour productivity growth during the nineties.

In addition, the results show that beyond ICTs, adoption of advanced process control and packaging technologies are also associated with higher productivity growth. For certain industries, adoption of advanced pre-processing technologies also increases firm performance.

Furthermore, the results emphasize that combinations of technologies that involve more than just ICTs are important. For example, adoption of advanced process control technology, by itself, has little effect on the productivity growth of a firm, but when combined with ICTs and advanced packaging technologies, the effect is significant. Similar effects are evident when firm performance is measured by market-share growth instead of productivity growth.

What is more significant is that these results still hold even when other activities and underlying characteristics of the firm are taken into account. We know that many factors determine whether a firm succeeds or fails. The food-processing survey has allowed us to measure not only technology use in a detailed way, but also to look at various other characteristics and competencies of a firm. We find that the association between technology use and productivity growth is robust to the inclusion or exclusion of the other activities and characteristics of the firm.

Other characteristics like the innovation stance of the firm, its business practices, and human resource strategies influence the extent to which a firm adopts new advanced technologies. But their direct impact on productivity growth or market-share growth is less than the indirect impact through their influence on technology use.

Does that mean that the other characteristics of the firm do not matter when it comes to firm growth? The answer is no. The capital intensity of a firm is positively and significantly related to productivity growth. Regression to the mean for the productivity growth equation is highly significant. A management team with a focus on improving the quality of its products by adopting an aggressive human resource strategy—by continuously improving the skill of its workforce through training and recruitment—is also associated with higher productivity growth. Market-share growth and the use of advanced technologies are significantly related, although productivity growth appears to have the strongest association with market-share growth.

Nevertheless, the predominant story that emerges from this analysis is that a high-technology orientation is closely associated with success. Moreover, this conclusion does not depend on the method that is used to measure success. Whether it is objective data on productivity and market share that are drawn from administrative records and linked to the survey, or the subjective evaluation of expert managers on their 'competitiveness', both show a strong association between the technological orientation of a plant and its performance.

Appendix A: Adoption of Advanced Technologies

The *1998 Survey of Advanced Technology in the Canadian Food Processing Industry* listed 60 advanced technologies covering nine functional areas. The nine functional areas are processing, process control, quality control, inventory and distribution, information and communications systems, materials preparation and handling, preprocessing, packaging, and design and engineering. The adoption rates of the 60 individual technologies are provided in Table A1, as well as the associated standard errors (Baldwin, Sabourin and West, 1999). Adoption rates of the functional technology groups are also provided. For example, 62% of Canadian food-processing establishments were using advanced processing technology in 1998, while only 14% of Canadian food-processing establishments were using aseptic processing, a specific type of advanced processing technology.

Table A1. Adoption of Advanced Technologies, 1998 (Percentage of Establishments Using the Technology)

Technology	Specific Technology	In Use	Standard Error
Processing	• Any	62	
Thermal preservation	• Aseptic processing	14	1.2
	• Retortable flexible packages	9	1.0
	• Infra red heating	3	0.5
	• Ohmic heating	1	0.3
	• Microwave or other high frequency heating	4	0.7
Non-thermal preservation	• Chemical Antimicrobials	16	1.3
	• Ultrasonic techniques	2	0.4
	• High Pressure Sterilization	9	1.0
	• Deep Chilling	25	1.5
Separation, concentration and water removal	• Membrane process (i.e. reverse osmosis)	5	0.7
	• Filter Technologies	15	1.2
	• Centrifugation	10	1.1
	• Ion exchange	3	0.5
	• Vacuum microwave drying	1	0.4
	• Water activity control	16	1.3
Additives or ingredients	• Bio-ingredients	14	1.2
	• Microbial cells	8	0.9
Other	• Electrotechnologies (i.e. electrodialysis)	1	0.4
	• Microencapsulation	1	0.3
Process Control	• Any	56	
	• Automated sensor based inspection/testing of materials/products	22	1.5
	• Automated Statistical Process Control	14	0.5
	• Machine Vision	9	0.7
	• Bar Coding control of product flow in plant	19	0.5
	• Programmable logic controllers	36	0.3
	• Computerized Process Control	32	1.4

Table A1. Adoption of Advanced Technologies, 1998 (Percentage of Establishments Using the Technology) **(cont'd...)**

Technology	Specific Technology	In Use	Standard Error
Quality Control	• Any	44	
	• Chromatography Testing	6	1.4
	• Monoclonal antibodies	3	1.1
	• DNA probes	1	0.9
	• Rapid Testing techniques	24	1.3
	• Automated Laboratory testing	13	1.1
	• Mathematical modelling of quality/safety	7	0.9
Inventory and Distribution	• Any	39	
	• Bar coding	34	1.6
	• Automated Product Handling	11	1.0
Information and Communications Systems	• Any	62	
	• Local Area Network (LAN)	43	1.7
	• Wide Area Network (WAN)	20	1.3
	• Inter-company computer networks	37	1.6
	• Internet for marketing and information	27	1.6
	• Internet for procurement, research, hiring, etc	27	1.6
Materials Preparation and Handling	• Any	31	
	• Integrated electronically controlled machinery	10	1.1
	• Individual, electronically controlled non-integrated machinery (i.e. robots)	10	1.0
	• Electronic detection of machinery failure	23	1.4
Pre-Processing	• Any	36	
	• Animal Stress Reduction (i.e. gas stunning)	3	0.6
	• Bran Removal before milling	2	0.4
	• Micro component separation	1	0.3
	• Electronic or ultrasonic grading	4	0.6
	• Collagen, colour or P.S.E. Probe	3	0.6
	• Near infrared (NIR) analysis	9	0.8
	• Colour assessment/sorting	17	1.3
	• Electromechanical defect sorting	4	0.6
	• Rapid testing techniques	19	1.3
Packaging	• Any	51	
	• Non-integrated electronically controlled packing machinery	29	1.5
	• Integrated electronically controlled packing machinery	15	1.2
	• Modified atmosphere	18	1.3
	• Laminates	18	1.3
	• Active packaging	5	0.8
	• Multi-layer materials	22	1.4
Design and engineering	• Any	20	
	• Computer-aided design and engineering (CAD/CAE)	18	1.2
	• CAD output to control manufacturing machines (CAD/CAM)	5	0.8
	• Computer aided simulation and prototype	3	0.5
	• Digital representation of CAD output used in procurement	2	0.4

Appendix B: Principal Component Analysis

Principal component analysis takes a set of variables (X_i) and creates a new set of variables—the principal components (PC_i). Each new variable, the principal component (PC_i), is a weighted average of the original variables, eg., $PC_i = \Sigma W_i * X_i$ where W_i are the weights. The weights are chosen so that the new variables exhaust the variance in the original set of variables and the new variables are orthogonal to one another. The eigenvectors for the first 15 principal components are provided in table B1.

Table B1. Eigenvectors for Technology Use Principal Components

Functional Technology	Specific Technology	TECH1	TECH2	TECH3	TECH4	TECH5	TECH6	TECH7	TECH8
Processing	- Aseptic processing	0.145	0.096	0.035	-0.197	0.096	0.165	0.003	0.080
Thermal	- Retortable flexible packages	0.056	0.193	0.096	-0.182	-0.045	-0.005	0.108	0.071
preservation	- Infra red heating	0.072	0.200	0.002	-0.067	-0.032	0.153	0.175	0.227
	- Ohmic heating	0.009	0.044	0.111	0.000	-0.089	0.071	0.046	0.274
	- Microwave or other high frequency heating	0.084	0.223	-0.008	-0.021	0.013	-0.079	0.274	-0.047
Non-thermal	- Chemical Antimicrobials	0.103	0.228	0.061	-0.038	0.043	0.002	0.028	-0.169
preservation	- Ultrasonic techniques	0.087	0.064	0.121	0.058	0.079	-0.129	0.117	-0.357
	- High Pressure Sterilization	0.046	0.201	0.127	0.096	0.006	0.260	0.087	0.044
	- Deep Chilling	0.058	0.126	0.319	-0.053	0.031	-0.022	-0.081	-0.005
Separation, concentration and water removal	- Membrane process (i.e. reverse osmosis)	0.084	0.266	-0.165	-0.018	-0.061	0.088	-0.199	0.088
	- Filter Technologies	0.130	0.242	-0.019	0.124	-0.109	0.167	-0.191	0.029
	- Centrifugation	0.105	0.205	-0.163	0.100	0.003	0.044	-0.333	-0.061
	- Ion exchange	0.070	0.240	-0.181	0.003	-0.075	0.055	0.007	0.027
	- Vacuum microwave drying	0.039	0.056	0.154	-0.008	-0.064	0.086	0.112	0.281
	- Water activity control	0.111	0.221	0.195	0.044	0.064	0.078	-0.047	-0.018
Additives or ingredients	- Bio-ingredients	0.116	0.144	-0.146	0.104	0.255	0.097	0.022	-0.018
	- Microbial cells	0.081	0.232	-0.003	-0.016	0.178	-0.042	-0.018	-0.136
Other	- Electrotechnologies (i.e. electrodialysis)	0.069	0.356	-0.108	-0.034	0.039	0.094	0.172	-0.012
	- Microencapsulation	0.036	0.021	0.003	-0.120	0.157	-0.003	0.087	-0.008
Process Control	- Automated sensor based inspection equipment	0.168	-0.035	0.039	0.222	-0.119	-0.062	-0.184	0.017
	- Automated Statistical Process Control	0.171	-0.137	0.006	0.107	-0.030	0.258	0.064	0.121
	- Machine Vision	0.112	-0.010	0.101	0.164	-0.187	0.203	-0.098	-0.007
	- Bar Coding control of product flow in plant	0.165	-0.094	0.163	-0.217	-0.129	0.041	-0.035	0.160
	- Programmable logic controllers	0.215	-0.066	-0.189	0.113	-0.050	-0.104	-0.050	0.001
	- Computerized Process Control	0.210	-0.041	-0.119	0.142	-0.092	-0.073	-0.048	0.063
Quality Control	- Chromatography Testing	0.110	0.111	-0.193	0.051	-0.054	-0.086	0.058	0.000
	- Monoclonal antibodies	0.089	-0.086	-0.096	-0.280	0.291	0.079	-0.017	0.114
	- DNA probes	0.050	0.002	0.108	0.214	0.210	-0.014	0.179	0.200
	- Rapid Testing techniques	0.185	-0.050	0.013	-0.025	0.194	-0.132	-0.226	0.002
	- Automated Laboratory testing	0.135	-0.068	-0.085	-0.061	0.118	0.051	-0.110	0.047
	- Mathematical modelling of quality	0.074	-0.066	0.068	0.077	-0.122	0.163	0.209	-0.101

Table B1. Eigenvectors for Technology Use Principal Components **(cont'd...)**

Functional Technology	Specific Technology	TECH1	TECH2	TECH3	TECH4	TECH5	TECH6	TECH7	TECH8
Inventory and Distribution	- Bar coding	0.128	-0.071	0.146	-0.282	-0.161	-0.017	-0.060	0.127
	- Automated Product Handling	0.134	-0.064	0.057	0.084	-0.243	0.208	-0.027	0.014
Information and Communications Systems	- Local Area Network (LAN)	0.190	-0.025	-0.093	-0.053	-0.128	-0.147	0.179	0.014
	- Wide Area Network (WAN)	0.173	-0.027	-0.139	0.024	0.001	-0.132	0.215	0.030
	- Inter-company computer networks	0.190	-0.043	-0.123	0.037	-0.082	-0.176	0.027	0.114
	- Internet for marketing and information	0.148	0.061	-0.005	-0.081	-0.243	-0.328	0.197	0.048
	- Internet for procurement, research, hiring, etc	0.106	0.093	-0.060	-0.106	-0.191	-0.331	0.122	0.097
Materials Preparation and Handling	- Integrated electronically controlled machinery	0.118	-0.031	0.000	0.022	-0.129	0.031	-0.062	-0.209
	- Individual,electronically controlled non-integrated machinery (i.e. robots)	0.134	-0.156	-0.032	-0.100	-0.033	0.254	0.090	-0.096
	- Electronic detection of machinery failure	0.190	-0.137	-0.105	0.110	-0.045	0.061	-0.030	-0.047
Pre-Processing	- Animal Stress Reduction (i.e. gas stunning)	0.023	0.059	0.211	-0.069	0.047	-0.117	-0.169	-0.116
	- Bran Removal before milling	0.046	-0.042	0.042	0.323	0.128	-0.076	-0.069	0.106
	- Micro component separation	0.044	-0.014	0.088	0.266	0.168	-0.100	0.021	0.076
	- Electronic or ultrasonic grading	0.086	-0.038	0.231	0.196	0.073	-0.084	-0.010	0.122
	- Collagen, colour or P.S.E. Probe	0.087	0.029	0.321	0.143	0.165	-0.199	0.140	-0.015
	- Near infrared (NIR) analysis	0.149	-0.036	-0.251	0.047	0.185	0.010	-0.015	0.158
	- Colour assessment/sorting	0.163	-0.099	0.121	0.057	0.177	-0.050	0.054	0.136
	- Electromechanical defect sorting	0.126	-0.057	0.124	0.054	-0.084	0.054	-0.100	0.116
	- Rapid testing techniques	0.177	0.034	-0.023	-0.099	0.236	-0.148	-0.135	0.037
Packaging	- Non-integrated electronically controlled packing machinery	0.190	-0.050	0.041	-0.081	-0.020	-0.015	0.023	-0.022
	- Integrated electronically controlled packing machinery	0.191	-0.162	0.045	0.002	0.003	0.074	0.036	0.000
	- Modified atmosphere	0.102	0.156	0.189	-0.172	-0.043	-0.095	-0.234	-0.086
	- Laminates	0.160	-0.105	0.073	-0.199	0.060	0.045	-0.129	-0.179
	- Active packaging	0.072	-0.013	0.214	-0.030	-0.069	0.051	0.071	-0.117
	- Multi-layer materials	0.201	-0.087	0.053	-0.111	0.061	-0.020	-0.106	-0.068
Design and engineering	- Computer-aided design and engineering (CAD/CAE)	0.216	-0.113	-0.054	-0.037	-0.074	-0.045	0.000	-0.139
	- CAD output to control manufacturing machines (CAD/CAM)	0.111	0.010	0.088	0.201	0.021	0.088	0.157	-0.265
	- Computer aided simulation and prototype	0.096	-0.021	-0.064	0.046	-0.095	0.082	0.145	-0.355
	- Digital representation of CAD output used in procurement	0.128	-0.154	-0.073	-0.162	0.285	0.223	0.216	-0.075
Eigenvalue		8.17	3.47	2.43	2.24	1.99	1.79	1.65	1.63
Explained variance (percent)		13.6	5.8	4.1	3.7	3.3	3.0	2.8	2.7

Table B1. Eigenvectors for Technology Use Principal Components **(cont'd...)**

Functional Technology	Specific Technology	TECH9	TECH10	TECH11	TECH12	TECH13	TECH14	TECH15
Processing	-Aseptic processing	0.001	-0.207	0.057	0.117	-0.155	-0.022	0.122
Thermal preservation	-Retortable flexible packages	0.283	-0.075	-0.004	-0.065	-0.155	-0.015	0.173
	-Infra red heating	-0.025	-0.174	-0.199	0.084	-0.107	-0.049	0.310
	-Ohmic heating	-0.136	0.155	-0.118	0.034	-0.140	-0.112	0.229
	-Microwave or other high frequency heating	-0.077	-0.109	0.057	-0.013	-0.193	0.139	0.029
Non-thermal preservation	-Chemical Antimicrobials	-0.045	-0.068	0.117	0.103	-0.041	-0.187	-0.269
	-Ultrasonic techniques	-0.304	0.094	0.092	0.080	-0.118	-0.074	0.135
	-High Pressure Sterilization	-0.120	0.232	0.129	-0.201	-0.033	-0.040	-0.006
	-Deep Chilling	0.115	-0.093	0.206	-0.006	0.161	0.135	-0.045
Separation, concentration and water removal	-Membrane process (i.e. reverse osmosis)	0.074	-0.004	-0.093	0.143	0.008	-0.080	-0.015
	-Filter Technologies	-0.074	0.069	0.038	0.100	0.121	-0.115	-0.110
	-Centrifugation	0.097	0.098	0.050	0.046	0.040	-0.099	0.069
	-Ion exchange	0.054	-0.013	0.054	0.267	0.160	0.351	-0.033
	-Vacuum microwave drying	0.060	0.389	0.198	-0.041	-0.158	0.053	-0.137
	-Water activity control	-0.135	0.034	-0.078	-0.005	0.062	-0.010	0.073
Additives or ingredients	-Bio-ingredients	0.040	-0.055	0.080	-0.144	0.095	-0.147	-0.233
	-Microbial cells	-0.005	0.008	-0.086	-0.321	0.015	-0.144	0.057
Other	-Electrotechnologies (i.e. electrodialysis)	-0.029	-0.094	-0.089	-0.111	0.103	0.107	0.093
	-Microencapsulation	-0.004	0.121	-0.344	-0.271	0.350	0.079	-0.116
Process Control	-Automated sensor based inspection equipment	0.039	-0.087	-0.021	-0.024	-0.150	0.164	0.023
	-Automated Statistical Process Control	0.061	-0.089	0.076	0.042	-0.107	0.161	-0.016
	-Machine Vision	-0.141	0.059	0.062	-0.077	-0.070	0.135	-0.091
	-Bar Coding control of product flow in plant	-0.008	-0.095	0.150	0.032	0.215	-0.148	-0.052
	-Programmable logic controllers	0.024	-0.032	0.002	-0.175	-0.201	-0.075	0.007
	-Computerized Process Control	-0.016	-0.027	-0.015	-0.109	-0.092	-0.025	0.038
Quality Control	-Chromatography Testing	0.017	-0.021	-0.026	0.159	0.165	0.229	-0.274
	-Monoclonal antibodies	0.055	0.143	0.218	0.109	0.029	-0.057	-0.066
	-DNA probes	0.275	-0.088	0.173	0.003	-0.117	-0.007	-0.329
	-Rapid Testing techniques	0.044	0.164	0.006	0.082	-0.188	-0.028	0.068
	-Automated Laboratory testing	0.029	0.248	0.045	-0.030	0.258	0.068	0.308
	-Mathematical modelling of quality	0.211	0.270	-0.028	0.023	-0.127	0.131	-0.060
Inventory and Distribution	-Bar coding	0.055	-0.151	0.062	0.033	0.245	-0.157	-0.024
	-Automated Product Handling	-0.030	-0.089	-0.005	-0.061	0.094	-0.196	-0.054
Information and Communications Systems	-Local Area Network (LAN)	-0.058	-0.086	0.038	-0.136	0.005	-0.215	0.006
	-Wide Area Network (WAN)	-0.098	-0.192	0.024	-0.068	0.053	-0.029	-0.134
	-Inter-company computer networks	-0.069	-0.043	0.196	-0.094	-0.011	-0.079	0.028
	-Internet for marketing and information	0.009	0.132	0.020	0.053	0.106	0.054	0.052
	-Internet for procurement, research, hiring, etc	0.129	0.257	0.039	0.077	0.043	-0.043	0.013

Table B1. Eigenvectors for Technology Use Principal Components **(cont'd...)**

Functional Technology	Specific Technology	TECH9	TECH10	TECH11	TECH12	TECH13	TECH14	TECH15
Materials Preparation and Handling	-Integrated electronically controlled machinery	0.073	0.185	0.150	-0.334	0.084	0.047	0.039
	-Individual, electronically controlled non-integrated machinery (i.e. robots)	-0.067	-0.096	0.178	-0.202	0.048	0.131	0.085
	-Electronic detection of machinery failure	-0.099	-0.003	0.019	-0.116	0.094	0.054	0.078
Pre-Processing	-Animal Stress Reduction (i.e. gas stunning)	-0.210	-0.151	0.244	0.045	0.086	0.215	-0.015
	-Bran Removal before milling	0.232	-0.071	-0.008	0.130	0.132	0.029	0.168
	-Micro component separation	0.319	-0.142	0.065	-0.156	0.139	-0.085	0.191
	-Electronic or ultrasonic grading	-0.151	-0.034	0.060	0.084	0.166	0.137	0.256
	-Collagen, colour or P.S.E. Probe	-0.076	0.009	-0.151	0.014	0.029	-0.021	-0.101
	-Near infrared (NIR) analysis	-0.091	0.066	-0.190	0.041	0.061	0.120	-0.015
	-Colour assessment/sorting	-0.257	0.129	-0.094	0.128	0.075	0.066	-0.083
	-Electromechanical defect sorting	-0.193	0.041	-0.336	0.108	-0.032	-0.209	-0.248
	-Rapid testing techniques	-0.086	0.131	0.087	0.019	-0.202	0.045	0.029
Packaging	-Non-integrated electronically controlled packing machinery	0.013	-0.036	-0.247	-0.128	-0.097	0.233	-0.017
	-Integrated electronically controlled packing machinery	-0.016	-0.227	-0.123	0.041	-0.029	0.153	-0.033
	-Modified atmosphere	0.108	-0.072	-0.084	-0.120	-0.135	0.175	-0.044
	-Laminates	0.134	-0.073	-0.165	0.020	-0.149	0.040	-0.063
	-Active packaging	0.256	0.161	-0.224	-0.002	0.178	0.031	-0.033
	-Multi-layer materials	0.214	0.046	-0.135	0.038	-0.120	-0.089	-0.047
Design and engineering	-Computer-aided design and engineering (CAD/CAE)	-0.013	0.022	0.063	0.177	0.060	-0.097	0.056
	-CAD output to control manufacturing machines (CAD/CAM)	0.115	-0.017	-0.028	0.260	0.075	-0.310	0.130
	-Computer aided simulation and prototype	0.110	0.083	-0.001	0.262	-0.012	0.077	0.051
	-Digital representation of CAD output used in procurement	-0.026	0.063	0.063	0.102	0.039	-0.026	0.064
Eigenvalue		1.48	1.35	1.31	1.30	1.22	1.19	1.15
Explained variance (percent)		2.5	2.3	2.2	2.2	2.0	2.0	1.9

Interpretation of the principal components is provided in Table B2.

Table B2. Interpretation of Principal Components and their Importance by Industry

Principal Component	Interpretation	Industry		Variance explained (%)
		Highest Scores	Lowest Scores	
Tech1	Emphasizes process control, information and communications and packaging technologies.	In dairy and 'other' food products	In bakery and fish	13.6
Tech2	Emphasizes advanced processing technology, of all types. Downplays robots, packaging machinery, statistical process control and CAD output.	In dairy and meat	In cereal	5.8
Tech3	Emphasizes pre-processing (except for near infrared analysis), non-thermal preservation, bar coding, and microwave drying and water activity control. Downplays separation and concentration processing, chromotography and near infrared analysis.	In meat and fish	In dairy, cereal and 'other' food products	4.1
Tech4	Emphasizes pre-processing, process control, and DNA probes. Downplays thermal preservation and advanced materials packaging, bar coding and monoclonal antibodies	In cereal and bakery	In meat and dairy	3.7
Tech5	Emphasizes quality control, bio-ingredients, rapid testing, digital CAD, and pre-processing. Downplays inventory and distribution, internet use & machine vision.	In dairy	In fruits & vegetables	3.3
Tech6	Emphasizes product handling, high-pressure sterilization, statistical process control, robots, machine vision, and digital CAD. Downplays information and communications, and rapid testing.	In fish and fruits & vegetables	In meat and 'other' food products	3.0
Tech7	Emphasizes information and communications, thermal preservation heating, simulation modeling, and design and engineering. Downplays separation techniques, sensor-based and rapid testing and advanced materials packaging.	In bakery	In dairy and meat	2.8
Tech8	Emphasizes infrared and ohmic heating, microwave drying, and DNA probes. Downplays design and engineering, ultrasonic techniques and chemical antimicrobials, and electronically controlled machinery.	In dairy and fruits & vegetables	In meat and 'other' food products	2.7
Tech9	Emphasizes flexible packages, DNA probes, simulation modeling, bran removal and micro component separation, and active and multi-layer materials packaging. Downplays ultrasonic techniques, colour assessment, defect sorting and animal stress reduction.	In bakery and dairy	In fruits & vegetables	2.5
Tech10	Emphasizes microwave drying, laboratory testing, simulation modeling, high-pressure sterilization, and internet use. Downplays aseptic processing, animal stress reduction and infra red heating.	In fish	In bakery and fruits & vegetables	2.3
Tech11	Emphasizes animal stress reduction, deep chilling, monoclonal antibodies, and microwave drying. Downplays microencapsulation, defect sorting, and packaging.	In meat	In 'other' food products	2.2
Tech12	Emphasizes design and engineering and ion exchange. Downplays microbial cells, microencapsulation, and robots.	In 'other' food products, fish and fruits & vegetables	In bakery and dairy	2.2
Tech13	Emphasizes microencapsulation, laboratory testing, and bar coding. Downplays thermal preservation, PLCs, and rapid testing.	In fish and cereal	In dairy	2.0
Tech14	Emphasizes ion exchange, chromoography, packaging machinery and animal stress reduction. Downplays CAD/CAM, inventory and distribution, defect sorting and LANs.	In fish	In fruits & vegetables and cereal	2.0
Tech15	Emphasizes thermal preservation, pre-processing separation and grading, and automated laboratory testing. Downplays chemical antimicrobials, bio-ingredients, chromotography, DNA probes and defect sorting.	In dairy and cereal	In fruits & vegetables, bakery and fish	1.9

Appendix C: Factor Analysis for Firm Competency Variables

Table C1. Factor Loadings for Firm Competency Factors

Variable	Factor Pattern	
	Factor 1	Factor 2
Markets		
- introducing new products in present markets	0.832	-0.471
- introducing current products in new markets	0.780	0.602
- introducing new products in new markets	0.906	-0.086
Technology		
- using technology developed by others	0.758	0.622
- developing new technology	0.865	-0.095
- improving existing technology	0.803	-0.485
Management/Human resources		
- continuously improving quality	0.695	0.589
- introducing innovative organizational structure	0.781	-0.387
- using information technology	0.801	-0.278
- continuously training staff	0.785	0.346
- introducing innovative compensation packages	0.767	-0.254
- recruiting skilled workers	0.778	0.051

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